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Journal of

The Mineralogical Society

INSTITUTED FEBRUARY 3, 1876.

EDITED BY L. J. SPENCER, M.A.

ASSISTED BY A COMMITTEE OF COUNCIL.

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THE MINERALOGICAL SOCIETY

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MINERALOGICAL SOCIETY.

(*Instituted February* 3, 1876.)

BYE-LAWS.

1. The object of the Mineralogical Society of Great Britain and Ireland, with which the Crystallological Society was amalgamated on December 11, 1883, shall be to advance the knowledge of Mineralogy, and also of Crystallography and Petrology.

2. The Society shall consist of Ordinary Members and Honorary Members.

Ordinary Members.

3. Every candidate for Ordinary Membership shall be proposed by two Ordinary Members, one, at least, of whom shall have personal knowledge of the candidate.

4. Elections to Ordinary Membership shall be made by the Council, and shall be confirmed at the ensuing general meeting by a majority consisting of three-fourths of the Members present and voting.

5. Ordinary Members shall pay an entrance fee of one guinea and an annual subscription of one guinea. Ordinary Members elected on or before November 13, 1900, shall be entitled to compound for the annual subscription by a single payment of ten guineas: Ordinary Members elected after that date shall be entitled to compound for the annual subscription by a single payment of fifteen guineas.

6. Annual Subscriptions shall be due on the first of January of each year, but Members elected after the first of October shall not be required to pay a subscription for the then current year.

7. The name of any Ordinary Member whose subscription is more than two years in arrear shall be brought before the Council, and an intimation that this action has been taken shall be communicated to the Member. After the expiration of at least one year from that date, the Council shall be empowered to erase the name from the List of Members.

Honorary Members.

8. Twenty persons, non-resident in the United Kingdom, may be elected Honorary Members. They shall pay neither entrance fee nor annual subscription.

9. Every candidate for Honorary Membership shall be proposed by two Members of the Council, and the election shall be by the Council, and shall be confirmed at the ensuing general meeting by a majority consisting of three-fourths of the Members present and voting.

Council.

10. The Society shall be governed by a Council, consisting of a President, two Vice-Presidents, a General Secretary, a Foreign Secretary, a Treasurer, an Editor of the Journal, and twelve Ordinary Members.

11. All members of the Society who have served the office of President shall be life-members of the Council.

12. The Council shall be elected annually at the Anniversary Meeting.

13. Four Ordinary Members of Council shall retire annually, and shall not be eligible for re-election until the next Anniversary Meeting.

14. The Council shall prepare a List of Members nominated for election as Officers and Ordinary Members of Council.

15. The election of Council shall be effected by the agency of voting papers containing the List nominated by the Council. They shall be sent by the General Secretary, at least four weeks before the Anniversary Meeting, to every Ordinary Member of the Society, and every such Member shall be entitled to substitute the names of any other Ordinary Members of the Society for those on the List.

16. The voting papers shall be returned by the Members to the General Secretary, and shall be examined at the Anniversary Meeting by two Scrutineers appointed by the Chairman, who shall on their report declare the result of the election. The voting papers need not be signed.

17. The Council shall have power to appoint Officers, and to co-opt Ordinary Members of Council to fill vacancies in the Council caused by death or resignation during the interval between two Anniversary Meetings.

18. Meetings of the Council shall be summoned by order of the President or the Council; at such meetings three shall be a quorum, of whom

one shall be either the President, a Vice-President, the Treasurer, or the General Secretary.

19. A Report of Council on the work and progress of the Society shall be submitted at each Anniversary Meeting.

Trustees.

20. Two or more Trustees shall be appointed by the Council, and the invested property of the Society shall stand in their names.

21. Composition-fees shall be treated as Capital: a Resolution of the Society at a general meeting, summoned with notice of a proposed disposition of property, shall be sufficient authority to the Trustees to give effect to such disposition; provided that a resolution of the Council shall be sufficient authority for any change of investment.

Meetings.

22. Meetings of the Society shall be summoned from time to time, as may be deemed necessary by the Council, or at the requisition of any ten Members of the Society. One of these meetings in each year shall be termed the Anniversary Meeting.

Journal.

23. The Numbers of the *Mineralogical Magazine and Journal of the Society* shall be issued at such intervals as the Council shall determine, and shall be sent, postage paid, to every Member of the Society.

Auditors and Balance Sheet.

24. Two Ordinary Members of the Society, one of whom is not a Member of the Council, shall be appointed annually by the Council to audit the accounts of the Society.

25. No auditor shall serve for more than three years in succession.

26. The audited Balance Sheet, after submission to the Council, shall be published in the Journal of the Society as early as possible in every year.

Expulsion of Members.

27. A majority consisting of three-fourths of the whole Council shall have power to expel a Member from the Society, but a Member who has been expelled shall have a right of appeal to the Society. Notice of such appeal to the Society shall be sent by such Member to the

General Secretary within four weeks of the expulsion, and the appeal shall be considered by the Society at the next Anniversary Meeting; a majority of the votes recorded at such Meeting sufficing to confirm or annul the decision of the Council.

Alteration of the Bye-Laws.

28. The Bye-laws may be altered only at an Anniversary Meeting, and only by a majority consisting of three-fourths of the Members present and voting. Notice of changes proposed to be made in the Bye-laws shall be communicated by the General Secretary to every Ordinary Member of the Society at least four weeks before the Anniversary Meeting at which they are to be considered.

Obligation Book.

29. Ordinary Members, by payment of their entrance fee, signify their acceptance of any Bye-laws approved by the Society; and every Member of the Society shall sign an Obligation Book.

LIST OF MEMBERS.

(*March*, 1908.)

HONORARY MEMBERS.

Year of Election.

1905 BAUMHAUER, Heinrich. Professor of Mineralogy in the University of *Freiburg, Switzerland.*

C[1] BERTRAND, Émile. 35, Boulevard des Invalides, *Paris.*

1895 BREZINA, Aristides. VII. Siebensterngasse 46, *Vienna.*

1895 BRÖGGER, Waldemar Christofer. Professor of Mineralogy and Geology, and Rector of the University, *Christiania.*

1879 BRUSH, George Jarvis. Yale University, *New Haven, Conn., U.S.A.*

1897 DANA, Edward Salisbury. Yale University, *New Haven, Conn., U.S.A.*

1877 GROTH, Paul Heinrich von. Professor of Mineralogy in the University of *Munich.*

1900 LACROIX, Alfred. Professor of Mineralogy in the Muséum d'Histoire Naturelle, *Paris.*

C[1] LANG, Victor von. Professor of Physics in the University of *Vienna.*

1898 LÉVY, Auguste Michel. Professor in the Collège de France, *Paris.*

1903 LIEBISCH, Theodor. Professor of Mineralogy in the University of *Berlin.*

1883 LUDWIG, Ernst. 9 Allgemeines Krankenhaus, *Vienna.*

1879 ROSENBUSCH, Harry. Professor of Mineralogy and Geology in the University of *Heidelberg.*

1877 STEENSTRUP, Knud Johannes Vogelius. Forchhammersvej 15[1], *Copenhagen.*

1903 STRÜVER, Giovanni. Professor of Mineralogy in the Royal University of *Rome.*

1879 TSCHERMAK, Gustav. The University, *Vienna.*

1880 WIIK, Fredrik Johan. *Helsingfors.*

1879 ZIRKEL, Ferdinand. Professor of Mineralogy and Geognosy in the University of *Leipzig.*

[1] C = Corresponding Member of the Crystallological Society at the time of the amalgamation of the two societies, December 11, 1883.

ORDINARY MEMBERS.[1]

A. Annual Subscribers.
L. Life-Members.
C. Belonged to the Crystallological Society at the time of the amalgamation of the two Societies, December 11, 1883.

	Year of Election.	
L	1888	Arnold-Bemrose, Henry Howe, J.P., M.A., Sc.D., F.G.S. *Ash Tree House, Osmaston Road, Derby.*
A	1881	Baker, Harry, F.C.S. *Epworth House, Maughland Lane, Runcorn, Cheshire.*
A	1904	Barker, Thomas Vipond, B.A., B.Sc. (Oxon.), F.C.S. *Exeter College, Oxford.*
L	1894	Barlow, William, F.R.S. *The Red House, Stanmore, Middlesex.*
L	1876	Barnett, Andrew Ketchan, F.G.S. 11 *Penrose Terrace, Penzance, Cornwall.*
L	1893	Barrow, George, F.G.S. Geological Survey of England, *The Museum,* 28 *Jermyn Street, London, S.W.*
L	1897	Beale, William Phipson, K.C., M.P., F.G.S., F.C.S. 10 *New Court, Carey Street, London, W.C.*
A	1894	Beringer, John Jacob, A.R.S.M., F.C.S., F.I.C. *School of Mines, Camborne, Cornwall.*
A	1894	Berkeley, The Rt. Hon. the Earl of, F.R.S. *Foxcombe, Boar's Hill, near Oxford.*
A	1906	Blake, George Stanfield, B.Sc., A.R.S.M., F.C.S. *Scientific and Technical Department, Imperial Institute, London, S.W.*
L	1876	Bonney, Rev. Thomas George, D.Sc., LL.D., F.R.S. Emeritus Professor of Geology in University College, London. 9 *Scroope Terrace, Cambridge.*
L	1897	Bowman, Herbert Lister, M.A., F.G.S., F.C.S. *Mineral Department, University Museum, Oxford.*
L	1876	Brown, Alexander Crum, M.D., D.Sc., F.R.S. Professor of Chemistry in the University of Edinburgh. 8 *Belgrave Terrace, Edinburgh.*
A	1901	Burls, Herbert Thomas, F.G.S. 11 *Foulis Terrace, Onslow Gardens, London, S.W.*

[1] Corrections for this List should be sent to the General Secretary, 35 Woodville Gardens, Ealing, London, W.

Year of Election.

L 1885 Butler, Francis Henry, M.A., A.R.S.M., L.S.A. (Lond.). 158 *Brompton Road, London, S.W.*

A 1903 Campbell, Donald Fraser, B.A., A.R.S.M., F.G.S. *Old Hunstanton, Norfolk.*

A 1876 Church, Arthur Herbert, M.A., D.Sc., F.R.S. Professor of Chemistry in the Royal Academy of Arts. *Shelsley, Ennerdale Road, Kew, Surrey.*

A 1888 Cole, Grenville A. J., M.R.I.A., F.G.S. Director of the Geological Survey of Ireland, Professor of Geology in the *Royal College of Science for Ireland, Dublin.*

L 1892 Collins, Henry F., A.R.S.M. 702 *Salisbury House, Finsbury Circus, London, E.C.*

L 1876 Collins, Joseph Henry, F.G.S. *Crinnis House, Par Station, Cornwall.*

L 1900 Coomaraswamy, Ananda K., D.Sc., F.L.S., F.G.S., M.R.A.S. *Norman Chapel, Broad Campden, Gloucestershire.*

A 1907 Crook, Thomas, A.R.C.Sc.I., F.G.S. *Scientific and Technical Department, Imperial Institute, London, S.W.*

L 1888 Crookes, Sir William, D.Sc., F.R.S. 7 *Kensington Park Gardens, London, W.*

A 1899 Cullis, Charles Gilbert, D.Sc., F.G.S. Assistant-Professor of Geology in the *Royal College of Science, South Kensington, London, S.W.*

L 1899 Currie, James, M.A., F.R.S.E. *Larkfield, Golden Acre, Edinburgh.*

L 1876 Danby, Thomas William, M.A., F.G.S. *The Crouch, Seaford, Sussex.*

L 1885 Daw, John W., *Walreddon Manor, Tavistock, Devon.*

L 1898 De Castro, J. Paul, M.A., F.C.S., F.I.C. *Laboratory and Assay Office, Effingham House,* 1 *Arundel Street, Strand, London, W.C.*

L 1891 Evans, John William, LL.B., D.Sc., F.G.S. 75 *Craven Park Road, Willesden Junction, London, N.W.*

L 1900 Fleischmann, Friedrich Noel Ashcroft, M.A., F.C.S. 4 *Orme Court, London, W.*

L C Fletcher, Lazarus, M.A., F.R.S. Keeper of Minerals in the British Museum (Natural History), Cromwell Road, London, S.W. 35 *Woodville Gardens, Ealing, London, W.*

L 1895 Fletcher, Rev. Mark, M.A., F.G.S. Demonstrator in Mineralogy in the Durham College of Science. *The*

	Year of Election.	
		Vicarage, North Sunderland, Chathill R.S.O., Northumberland.
L	1902	Flett, John Smith, M.A., D.Sc., F.R.S.E., F.G.S. Geological Survey of England. *The Museum, 28 Jermyn Street, London, S.W.*
A	1876	Geikie, Sir Archibald, D.Sc., D.C.L., LL.D., Sec.R.S. Formerly Director-General of the Geological Survey of the United Kingdom. *Shepherd's Down, Haslemere, Surrey.*
A	1876	Geikie, James, LL.D., D.C.L., F.R.S. Professor of Geology and Mineralogy in the University of Edinburgh. *Kilmorie, Colinton Road, Edinburgh.*
L	1881	Gibb, T. J., 37 *Old Jewry, London, E.C.*
L	1902	Giles, William B., F.I.C. *The Grange, Leyton, Essex.*
L	1886	Goldschmidt, Dr. Victor, Professor of Mineralogy in the University of Heidelberg. 9 *Gaisbergstrasse, Heidelberg, Germany.*
A	1905	Goodchild, Wilbert, M.B., Ch.B. (Edin.). *Blencathra Sanatorium, Threlkeld, Penrith, Cumberland.*
A	1895	Gordon, Rev. John More, F.G.S. *St. John's Vicarage, Redhill, Surrey.*
A	1903	Grabham, George Walter, M.A., F.G.S. Geologist to the Sudan Government. *Department of Works, Khartoum, Sudan, Egypt.*
L	1892	Gregory, John Walter, D.Sc., F.R.S. Professor of Geology in the *University of Glasgow.*
A	1900	Hall, Arthur Lewis, B.A., F.G.S. *Geological Survey Office, Pretoria, Transvaal.*
A	1908	Harger, Harold S., F.G.S. *P. O. Box* 1945, *Johannesburg, Transvaal.*
A	1885	Harker, Alfred, M.A., F.R.S. Fellow of St. John's College, Cambridge. *St. John's College, Cambridge.*
A	1898	Hartley, Ernald George Justinian, B.A., F.C.S. *The Bungalow, Boar's Hill, near Oxford.*
L	1900	Hartley, Harold Brewer, M.A., F.C.S. *Balliol College, Oxford.*
A	1879	Henson, Samuel, 97 *Regent Street, London, W.*
L	1907	Hilton, Harold, M.A. 73 *Platts Lane, Hampstead, London, N.*
A	1888	Hoffmann, G. Christian, LL.D. *Care of A. F. May, Esq., Carleton Chambers,* 74 *Sparts Street, Ottawa, Canada.*

	Year of Election.	
L	1896	Holland, Thomas Henry, A.R.C.S., F.R.S. Director of the Geological Survey of India. *Geological Survey Office, Calcutta, India.*
A	1902	Howe, John Allen, B.Sc., F.G.S. Curator of the Museum of Practical Geology. *The Museum, 28 Jermyn Street, London, S.W.*
A	1876	Hudleston, Wilfrid Hudleston, M.A., F.R.S. 8 *Stanhope Gardens, South Kensington, London, S.W.*
A	1878	Hughes, Thomas McKenny, M.A., F.R.S. Professor of Geology in the University of Cambridge. *Ravensworth, Brooklands Avenue, Cambridge.*
A	1893	Hussak, Dr. Eugen. 1 *Rua Verona, São Paulo, Brazil.*
L	1890	Hutchinson, Arthur, M.A., Ph.D., F.C.S., F.G.S. Demonstrator of Mineralogy in the University of Cambridge. *Pembroke College, Cambridge.*
A	1899	Jackson, Henry, M.A., B.Sc., F.C.S. *Downing College, Cambridge.*
A	1905	Jones, Bernard Mouat, B.A. *Government College House, Lahore, India.*
A	1908	Jones, Owen Thomas, M.A., B.Sc., F.G.S. Geological Survey of England. *The Museum, 28 Jermyn Street, London, S.W.*
L	1884	Judd, John Wesley, C.B., LL.D., F.R.S. Formerly Professor of Geology in, and Dean of, the Royal College of Science, South Kensington, S.W. *Orford Lodge, 30 Cumberland Road, Kew, Surrey.*
L	1876	Kinch, Edward, F.C.S., F.I.C. Professor of Chemistry in the *Royal Agricultural College, Cirencester.*
L	1876	Kitto, Benedict, F.I.C., F.G.S. 26 *Lancaster Road, Finsbury Park, London, N.*
A	1907	Krantz, Friedrich Ludwig Robert, Ph.D. 36 *Herwarth-Strasse, Bonn, Rhenish Prussia.*
A	1885	Kunz, George Frederick, M.A., Ph.D., F.G.S. 401 *Fifth Avenue, New York City, U.S.A.*
A	C	Lewis, William James, M.A., F.C.S. Professor of Mineralogy in the University of Cambridge. *The New Museums, Cambridge.*
A	1886	Lindsey, C. R., B.Sc. 11 *Brantingham Road, Whalley Range, Manchester.*
L	C	Liveing, George Downing, M.A., D.Sc., F.R.S. Professor of Chemistry in the University of Cambridge. *Newnham, Cambridge.*

	Year of Election.	
L	1876	Liversidge, Archibald, M.A., LL.D., F.R.S. Formerly Professor of Chemistry in the University of Sydney, New South Wales. *The United University Club, Suffolk Street, Pall Mall, London, S.W.*
A	1879	Louis, Henry, M.A., A.R.S.M., F.G.S. Professor of Mining in the *Durham College of Science, Newcastle-on-Tyne.*
A	1902	McGrigor, George Duncan, F.R.G.S. 25 *Charles Street, St. James's, London, S.W.*
A	1908	McLintock, William Francis Porter, B.Sc. *The Museum,* 28 *Jermyn Street, London, S.W.*
A	1902	Maitland, Andrew Gibb, C.E., F.G.S. Government Geologist. *Geological Survey, Perth, Western Australia.*
L	1881	Mallet, Frederick Richard, F.G.S., F.C.S., F.I.C. 20 *King's Avenue, Ealing, London, W.*
A	1907	Mears, J. B., L.R.C.P., L.R.C.S. (Edin.). *Woodburn Sanatorium, Morningside, Edinburgh.*
A	1902	Mennell, Frederic Philip, F.G.S. Curator of the *Rhodesia Museum, Bulawayo, Rhodesia.*
L	1876	Merry, J. S., *Swansea, South Wales.*
L	C	Miers, Henry Alexander, M.A., D.Sc., F.R.S. Professor of Mineralogy in the University of Oxford. *Magdalen College, Oxford.*
L	1876	Morris, James, 6 *Windsor Street, Swansea, South Wales.*
A	C	Müller, Hugo, Ph.D., LL.D., F.R.S. 13 *Park Square East, Regent's Park, London, N.W.*
A	1907	Parkinson, John, M.A., F.G.S. 30 *Lensfield Road, Cambridge.*
L	1880	Pearce, Richard, Ph.D., F.G.S. *Care of G. B. Pearce, Esq., The Beeches, Hayle, Cornwall.*
L	1899	Pollard, William, M.A., D.Sc., F.G.S., F.C.S. Geological Survey of England. *The Museum,* 28 *Jermyn Street, London, S.W.*
A	1891	Pope, William Jackson, F.R.S. Professor of Chemistry in the Municipal School of Technology, Manchester. *Corchester, Bramhall, Cheshire.*
A	1887	Pringle, Alexander, M.A., B.Sc. *The Museum,* 28 *Jermyn Street, London, S.W.*
L	1887	Prior, George Thurland, M.A., D.Sc., F.G.S. *British Museum (Natural History), Cromwell Road, London, S.W.*
A	1903	Rastall, Robert Heron, M.A., F.G.S. *Christ's College, Cambridge.*

	Year of Election.	
A	1876	Rudler, Frederick William, I.S.O., F.G.S. 18 *St. George's Road, Kilburn, London, N.W.*
A	1902	Russell, Arthur Edward Ian Montagu. *Swallowfield Park, Reading.*
A	1908	Schröder, Robert. 17 *Leopoldstrasse, Heidelberg, Germany.*
L	1876	Scott, Robert Henry, M.A., D.Sc., F.R.S. 6 *Elm Park Gardens, London, S.W.*
A	1903	Scrivenor, John Brooke, M.A., F.G.S. Geologist to the Federated Malay States. *Kuala Lumpur, Federated Malay States.*
A	1884	Seligmann, Gustav. 6 *Neustadt, Coblenz, Rhenish Prussia.*
L	1897	Smith, George Frederick Herbert, M.A., D.Sc., F.G.S., F.R.A.S. *British Museum* (*Natural History*), *Cromwell Road, London, S.W.*
A	1897	Sollas, William Johnson, M.A., D.Sc., LL.D., F.R.S. Professor of Geology in the University of Oxford. *The Museum, Oxford.*
A	C	Solly, Richard Harrison, M.A. *Hôtel Belle Ile, Cadenabbia, Lago di Como, Italy.*
A	1894	Spencer, Leonard James, M.A., F.G.S. *British Museum, (Natural History), Cromwell Road, London, S.W.*
A	1878	Spezia, Giorgio, Professor of Mineralogy in the University, *Turin, Italy.*
A	C	Story-Maskelyne, Mervin Herbert Nevil, M.A., D.Sc., F.R.S. Late Professor of Mineralogy in the University of Oxford. *Basset Down House, Swindon, Wilts.*
A	1883	Teall, J. J. Harris, M.A., D.Sc., F.R.S. Director of the Geological Survey of Great Britain and of the Museum of Practical Geology. *The Museum,* 28 *Jermyn Street, London, S.W.*
A	1903	Thomas, Herbert Henry, M.A., B.Sc., F.G.S. Geological Survey of England. *The Museum,* 28 *Jermyn Street, London, S.W.*
L	1877	Trechmann, Charles Otto, J.P., Ph.D., F.G.S. *Hudworth Tower, Castle Eden, Co. Durham.*
A	1891	Tutton, Alfred Edwin Howard, M.A., D.Sc., F.R.S. 41 *Ladbroke Square, London, W.*
L	1894	Watts, William Whitehead, M.A., M.Sc., F.R.S. Professor of Geology in the *Royal College of Science, South Kensington, S.W.*

	Year of Election.	
L	1895	WEBB, R. C.
L	1901	WESTON, Digby, St. A. P., Lieutenant R.N. 19 *Earl's Court Square, South Kensington, S.W.*
L	1876	WILLS, Joseph Lainson, F.C.S. 133 *Midwood Street, Brooklyn, N.Y., U.S.A.*
L	1896	WILLS, Louis.
A	1904	WOODGATE, John, M.I.M.M. *Care of Woodgate, Sons, & Co.*, 2 *Rumford Place, Liverpool.*
L	C	WOODWARD, Charles J., B.Sc., F.G.S. *The Lindens, St. Mary's Road, Harborne, Birmingham.*
A	1902	YOUNG, Alfred Prentice, Ph.D., F.G.S. *Care of Messrs. Grindley & Co.*, 55 *Parliament Street, London, S.W.*

PROCEEDINGS

OF THE

MINERALOGICAL SOCIETY.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, November 12, 1907.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

Dr. Friedrich Ludwig Robert Krantz was elected an Ordinary Member of the Society.

The following were selected as the dates of Meeting for the year 1908:—Tuesdays, January 21, March 17, June 16, November 17, the last to be the Anniversary Meeting.

The draft annual report of Council, submitted by the Acting Secretary, was approved.

The announcement was made of the death of Professor Carl Klein, Honorary Member.

ANNIVERSARY MEETING.

Held in the Apartments of the Geological Society, November 12, 1907.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

Twenty-six Members were present.

The election of Dr. F. Krantz, of Bonn, to the Ordinary Membership was confirmed.

The scrutineers reported that thirty-three voting papers had been returned, and that the List as nominated by the Council was approved, namely:—

President. Prof. H. A. Miers, M.A., D.Sc., F.R.S.

Vice-Presidents. Prof. W. J. Lewis, M.A., F.C.S.
Prof. G. D. Liveing, M.A., D.Sc., F.R.S.

Treasurer. W. Phipson Beale, K.C., M.P., F.G.S., F.C.S.

General Secretary. L. Fletcher, M.A., F.R.S.

Foreign Secretary. Prof. W. W. Watts, M.A., F.R.S.

Editor of the Journal. L. J. Spencer, M.A., F.G.S.

Ordinary Members of Council.

W. Barlow, F.G.S., F.C.S.
J. J. Beringer, A.R.S.M., F.C.S.
J. P. De Castro, M.A., F.C.S.
J. S. Flett, M.A., D.Sc., F.R.S.E.
H. B. Hartley, M.A., F.C.S.
B. Kitto, F.I.C., F.G.S.
G. T. Prior, M.A., D.Sc., F.G.S.
F. W. Rudler, I.S.O., F.G.S.
Arthur Russell.
G. F. H. Smith, M.A., D.Sc., F.G.S.
A. E. H. Tutton, M.A., D.Sc., F.R.S.
A. P. Young, Ph.D., F.G.S.

The following Annual Report of Council was read:—

The Council are once more able to state that during the past year the Scientific activity and financial prosperity of the Society have been fully maintained.

During the year the usual four meetings have been held (by kind permission) in the Apartments of the Geological Society, Burlington House, W.; and two numbers of the Journal (No. 66 published in February and No. 67 published in September), containing twenty-three papers, have been issued.

During the session 1906–7 the Society has lost by death one Honorary Member (Prof. C. Klein) and one Ordinary Member (Mr. J. F. Walker), while five Ordinary Members have been elected. A total accession of four Ordinary Members has thus to be recorded. This raises the total number of Members on November 11, 1907, to 126; of whom eighteen are Honorary Members and 108 are Ordinary Members. Of the latter, fifty-one have compounded for their annual subscription.

As regards the financial position of the Society, the Balance Sheet of the year ending December 31, 1906, shows that the assets of the Society (exclusive of the Library and the Stock of the Journal) amounted to £707 12*s.* 1*d.*, and that the liabilities amounted to £15 8*s.* 4*d.* The value of the Stock invested in the name of the Trustees of the Society was on that date £601 1*s.* 3*d.*, corresponding to £11 15*s.* 8*d.* for each Life-Member.

The Society was represented at the celebration of the Centenary of the Geological Society of London by the President, Prof. H. A. Miers, who presented an address.

On the motion of Mr. C. J. Woodward, seconded by Mr. T. V. Barker, the Report was adopted.

Announcement was made of the death of Prof. C. Klein.

A vote of thanks to the Council of the Geological Society for permission to meet in the Apartments of the Society was carried.

The following papers were read:—

1. On Hopeite and other zinc phosphates and associated minerals from Rhodesia: by Mr. L. J. Spencer (p. 1).

2. The question of a relation between isomorphous miscibility and parallel growth of crystals: by Mr. T. V. Barker (p. 42).

3. Notes on zeolites from Cornwall and Devon: by Mr. Arthur Russell.

4. Note on the crystallization of potassium bichromate: by Prof. H. A. Miers (p. 39).

5. On various minerals from the Lengenbach quarry and the Ofenhorn, Binnenthal: by Mr. R. H. Solly.

6. Scalenohedral crystals of haematite from Vesuvius: by Dr. H. J. Johnston-Lavis and Mr. L. J. Spencer (p. 54).

The following specimens were exhibited:—

A fine collection of zeolites from the neighbourhood of Belfast, by Mr. F. N. A. Fleischmann; reconstructed rubies, by Dr. G. F. Herbert Smith; a specimen of artificial haematite, by Mr. C. J. Woodward; a new meteoric stone from Simondium, Cape Colony, by Dr. G. T. Prior.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, January 21, 1908.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

Mr. W. F. P. McLintock was elected an Ordinary Member of the Society.

Announcement was made of the resignation of Mr. B. H. Woodward.

Mr. J. P. De Castro and Dr. J. W. Evans were appointed auditors of the accounts for the year ending December 31, 1907.

GENERAL MEETING.

Held in the Apartments of the Geological Society, January 21, 1908.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

Nineteen Members and two Visitors were present.

The resignation of Mr. B. H. Woodward was announced, and the election of Mr. W. F. P. McLintock to the Ordinary Membership of the Society was confirmed.

The following papers were read:—

1. On Zeolites from the neighbourhood of Belfast: by Mr. F. N. A. Fleischmann.

2. On Strüverite and its relation to Ilmenorutile: by Dr. G. T. Prior and Dr. F. Zambonini (p. 78).

3. Twin-structure: by Dr. J. W. Evans.

4. On a simple method of drawing crystals of calcite and other rhombohedral crystals, and of deducing the relations of their symbols: by Prof. W. J. Lewis (p. 62).

5. On the structure of Perovskite from the Burgumer Alp, Pfitschthal, Tyrol: by Mr. H. L. Bowman.

Specimens of Zeolites were exhibited by Mr. Fleischmann in illustration of his paper; and a rhombohedron of Iceland-Spar showing multiple images by Mr. Abraham Booth.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, March 17, 1908.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

The death of Dr. H. C. Sorby, the first President of the Society, was announced.

Messrs. Harold S. Harger, Owen Thomas Jones, and Robert Schröder (of Heidelberg) were elected Ordinary Members of the Society.

The audited Balance Sheet for the year ending December 31, 1907, was submitted and approved.

Mr. L. J. Spencer reported that he had forwarded, on behalf of the Society, 914 slips relative to mineralogical, crystallographical, and petrological papers and books, published in the United Kingdom during 1907, to the Central Bureau of the International Catalogue of Scientific Literature.

GENERAL MEETING.

Held in the Apartments of the Geological Society, March 17, 1908.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

Thirty-one Members and four Visitors were present.

The elections of Messrs. H. S. Harger, O. T. Jones, and R. Schröder, to the Ordinary Membership were confirmed.

THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY.

No. 68. April, 1908. Vol. XV.

On Hopeite and other zinc phosphates and associated minerals from the Broken Hill mines, North-Western Rhodesia.

By L. J. Spencer, M.A., F.G.S.

Assistant in the Mineral Department of the British Museum.

[Read November 12, 1907.]

THE new and remarkable mineral locality known as Rhodesia Broken Hill is situated in North-Western Rhodesia, at a distance of about 300 miles to the north-east of the Victoria Falls, and at the present terminus of the Cape to Cairo Railway. The outcrop of lead and zinc ore which occurs here was accidentally discovered in January, 1902, by Mr. T. G. Davey, while he was prospecting the country for copper. Rising out of the flat surrounding country is a series of low hills or kopjes, the largest of them being about 90 feet in height; and these consist almost entirely of oxidized ore. The surrounding rocks are mainly crystalline limestones with some beds of sandstone, conglomerate, and phyllite.

The ordinary type of ore of which the kopjes consist is compact and of a light yellowish colour. It is composed of an intimate intermixture of zinc silicate (hemimorphite) and lead carbonate (cerussite) with variable amounts of interspersed iron hydroxide (limonite). Crystal-lined cavities are of frequent occurrence in this ore. In the work of exploration, one of the tunnels driven through Kopje No. 1 broke into a large cavern, measuring about 24 × 80 feet. In this cave were found bones of recent animals, together with stone implements and other evidences of

the former presence of man[1]. It is on the bone-breccia in this cave that the crystals of hopeite are found in association with vanadinite. Most of the other crystallized minerals (tarbuttite, parahopeite, descloizite, pyromorphite, &c.) occur in cellular limonite in Kopje No. 2, which is the largest hill of the group. There are thus at this locality two quite distinct occurrences of zinc phosphates.

Most of the specimens which I have examined were very kindly placed at my disposal by Mr. Percy C. Tarbutt, one of the directors of the Broken Hill Exploration Company. Not only has Mr. Tarbutt generously presented the best of his specimens to the British Museum collection and to several other museums, but he has also allowed me the free use of the many specimens which passed through his hands. Another extensive collection of specimens from Broken Hill was acquired for the British Museum from Dr. A. E. Salter, to whom they had been sent by one of his former pupils. Through the kindness of Mr. Alfred Bromwich, I have also been able to examine the specimens exhibited in the Rhodesia Museum at the London offices of the British South Africa Company (the 'Chartered Company'). A few other specimens, independently received by Dr. A. Hutchinson at the Cambridge Mineralogical Museum, and by the Royal Scottish Museum at Edinburgh, have also been submitted to me.

The following is a list of the several mineral species, which I have detected on the specimens :—

Hopeite (p. 3).
Parahopeite (p. 18).
Tarbuttite (p. 22).
Descloizite (p. 31).
Vanadinite (p. 33).
Pyromorphite (p. 33).
Hemimorphite (p. 34).
Calamine (p. 35).
Hydrozincite ? (p. 35).
Cerussite (p. 36).
Limonite (p. 37).
Wad (p. 37).
Quartz (p. 37).
Galena (p. 37).
Blende (p. 38).

In addition to the minerals mentioned above, there are no doubt others present at the locality. Some of the material is so minutely crystallized and so intermixed that it was not always possible to determine the species satisfactorily. An undetermined mineral, occurring as small, bright-green (monoclinic ?) crystals, appears to be a copper phosphate.

[1] A preliminary account of these remains has been published by F. P. Mennell and E. C. Chubb, Geol. Mag., 1907, dec. 5, vol. iv, pp. 443–448. A paper on the cave deposits prepared by Mr. Franklin White for the Rhodesia Scientific Association was very kindly sent to me by the author in typescript.

Hopeite.

The mineral hopeite has hitherto been known from only a single locality, namely the zinc-mine of Altenberg or Vieille Montagne in the neutral territory of Moresnet, between Liège and Aachen. It was found here about the year 1820[1], and apparently no specimens have been obtained since that time, although mining operations have been for a long period extensively carried on at the locality.

Specimens submitted to the Abbé Haüy about 1821 were classed by him as a variety of stilbite[2]. In the same year a specimen was sent to Sir David Brewster, and in it he recognized a new mineral species, which he named hopeite, after Dr. Thomas Charles Hope (1766–1844), professor of chemistry at Edinburgh. Very little material was available for examination, although an effort was made to obtain a further supply. It was therefore not possible to determine the chemical composition of the new mineral, but a blowpipe examination by N. G. Nordenskiöld suggested that it was a hydrated phosphate or borate of zinc with an earthy base and some cadmium. A. Lévy (1843) also determined the presence of zinc; but A. Damour (1879), working on only two milligrams of material, was the first to prove the mineral to be a phosphate of zinc.

In consequence of this determination by Damour, C. Friedel and E. Sarasin, who had previously successfully prepared several mineral phosphates, attempted the artificial preparation of hopeite; they obtained small crystals with the angles of hopeite, which on analysis were found to have the composition $Zn_3P_2O_8.4H_2O$.

Crystalline scales having this composition had indeed been previously prepared by H. Debray[3] in 1861, but as these were not determined crystallographically they were not identified with hopeite. W. Heintz[4] in 1867 had gone a step further, for he had ascertained, under the microscope, that crystals having this composition are orthorhombic. It should also be noted here that W. Skey[5], in 1869, had prepared a crystalline phosphate of zinc, to which he gave the formula $Zn_3P_2O_8.5H_2O$, and which

[1] A. Des Cloizeaux, 'Manuel de Minéralogie,' 1893, vol. ii, p. 516.

[2] A specimen in the Turner collection was so labelled, with a figure of a crystal, in the handwriting of Haüy (Brewster, 1824); and there also is an isolated crystal in the Haüy collection in the Muséum d'Histoire Naturelle at Paris (Des Cloizeaux, 1879). There is no mention of the mineral in Haüy's 'Traité de Minéralogie' (2nd edit., 1822).

[3] H. Debray, Ann. Chimie et Physique, Paris, 1861, ser. 3, vol. lxi, p. 436.

[4] W. Heintz, Ann. Chemie u. Pharmacie, 1867, vol. cxliii, p. 356.

[5] W. Skey, Trans. New Zealand Inst., 1869, vol. ii, p. 146; Chem. News, 1870, vol. xxii, p. 61.

he called artificial hopeite; but, as he gives no particulars, it is not clear how he arrived at this conclusion. Quite recently (1904), Baron A. de Schulten has prepared artificial crystals of hopeite measuring $4{\cdot}4 \times 1 \times 0{\cdot}6$ mm., from which he was able to determine the crystallographic constants with accuracy.

Several other phosphates of zinc have been prepared in a crystalline condition, and in this connexion mention may be made of those which have been determined crystallographically:—

The anhydrous salt, $Zn_3P_2O_8$, in rhombic prisms.[1]

The acid phosphate, $H_4ZnP_2O_8.2H_2O$, in large, anorthic crystals.[2]

Literature of Hopeite.

D. Brewster, 1822. 'New mineral from Aachen, near Altenberg.' Edinburgh Phil. Journ., vol. vi, p. 184.

(A preliminary note, initialled 'D. B.,' stating the mineral to be distinct from stilbite.)

D. Brewster, 1824. 'Description of hopeite, a new mineral, from Altenberg, near Aix-la-Chapelle.' Trans. R. Soc. Edinburgh, vol. x, pp. 107–111. (With crystallographic characters by W. Haidinger, and blowpipe reactions by N. G. Nordenskiöld.)

The title of this paper, read on June 17, 1823, is quoted in Edinburgh Phil. Journ., 1823, vol. ix, p. 186, where the name hopeite first appears in print. The paper was published in 1824, and was abstracted in various journals of that date, but the date on the title-page of volume x of the Edinburgh Transactions is 1826.

An account, with slight variations and additions, is given in F. Mohs's 'Grund-Riss der Mineralogie,' 1824, part 2, p. 682, and by W. Haidinger in his English translation of this work (1825, vol. iii, p. 109); also by Haidinger in Ann. Phys. Chem. (Poggendorff), 1825, vol. v, p. 169.

A. Lévy, 1837. 'Description d'une collection de minéraux formée par M. Henri Heuland, et appartenant à M. Ch. Hampden Turner . . .' London, vol. iii, p. 230, plate LXXIII.

Description of a single specimen. The prism angle he gives as $mm''' = 59° 45'$.

A. Lévy, 1843. 'Description de plusieurs espèces minérales appartenant à la famille du zinc.' Ann. des Mines, Paris, ser. 4, vol. iv, pp. 507–520. (Hopeite on pp. 517–520.)

This paper was read under a slightly different title in 1840 (Comptes Rendus Acad. Sci. Paris, vol. x, p. 197), and extracts only were published after the author's death in 1841.

A. Damour [and A. Des Cloizeaux], 1879. 'Nouveaux essais sur la hopéite.' Bull. Soc. Min. de France, vol. ii, pp. 131–135.

A re-examination of Haüy's crystal.

[1] A. de Schulten, Bull. Soc. Chim. Paris, 1889, ser. 3, vol. ii, p. 300.

[2] W. Demel, Sitz.-Ber. Akad. Wiss. Wien, math.-naturw. Cl., 1879, vol. lxxix, Abth. II, p. 649; Ber. Deutsch. chem. Ges., 1879, Jahrg. xii, p. 1171; compare abstract in Zeits. Kryst. Min., vol. v, p. 653.

C. Friedel and E. Sarasin, 1879. 'Sur la composition de la hopéite.' Bull. Soc. Min. de France, vol. ii, pp. 153–156.

G. Cesàro, 1898 'Description des minéraux phosphatés, sulfatés et carbonatés du sol Belge.' Mém. Acad. R. Sci. etc. Belgique, vol. liii, pp. 1–136. (Hopeite on pp. 18–20.)

A. de Schulten, 1904. 'Production artificielle de la hopéite.' Bull. Soc. franç. Min., vol. xxvii, pp. 100–103.

H. Buttgenbach, 1906. 'Hopéite de Moresnet.' Ann. Soc. Géol. Belgique, vol. xxxiii, Mém. pp. 9–11.

In striking contrast to its sparing occurrence at the original locality, hopeite occurs in considerable abundance at the new Rhodesian locality. Almost all specimens of the bone-breccia from the cave in Kopje No. 1 are encrusted with crystals of the mineral.

The brilliant, water-clear crystals, of all sizes up to about a centimetre in length, are scattered singly in great numbers over the surface of the bone-breccia, or are grouped in showy clusters. These crystals are always perfectly colourless and transparent with a bright, vitreous lustre; and are invariably associated with vanadinite (p. 33). The hopeite crystals rest upon the vanadinite or upon a thin, yellowish-white crust which coats the surface of the bone-breccia. This crust averages about $\frac{1}{4}$ mm. in thickness, and usually consists of two layers; a lower one of finely fibrous hemimorphite, and an upper one of very minutely crystallized tarbuttite, hemimorphite, or calamine, or of all three of these mixed together (p. 30). On some specimens of this type the more distinct crystals of hopeite are associated with minute tufts of colourless needles of hopeite. Similar tufts of acicular hopeite were also found in some of the cavities in the bone-breccia and inside bones and teeth.

Other specimens, of rather a different type, consist wholly of a close aggregate of hopeite crystals with little or no matrix and no associated minerals. These masses of pure hopeite are of considerable size, and may weigh several pounds. The crystals are of two kinds. The upper portion of the specimens consists of large crystals, measuring up to 2 cm. across, which are white and translucent; these are pronouncedly tabular in habit parallel to the macropinacoid, on which planes the lustre is markedly pearly. On the free surface of the specimens these large crystals have been considerably corroded, presenting a smooth, rounded surface. The lower portion of the specimens consists of an aggregate of much smaller hopeite crystals of a pale yellowish colour and with a tendency to divergent grouping. Smaller specimens of this type may show only one or other of these two kinds of crystals.

Crystallography.—The crystals of hopeite are orthorhombic, and, as

represented in the accompanying figures (fig. 1), are very simple in habit. According to the greater or lesser width of the faces of the macropinacoid $a\{100\}$, the crystals are tabular or prismatic in habit. Very often the crystals present an unsymmetrical or hemimorphic appearance, owing to the suppression or small development of two adjacent pyramidal planes

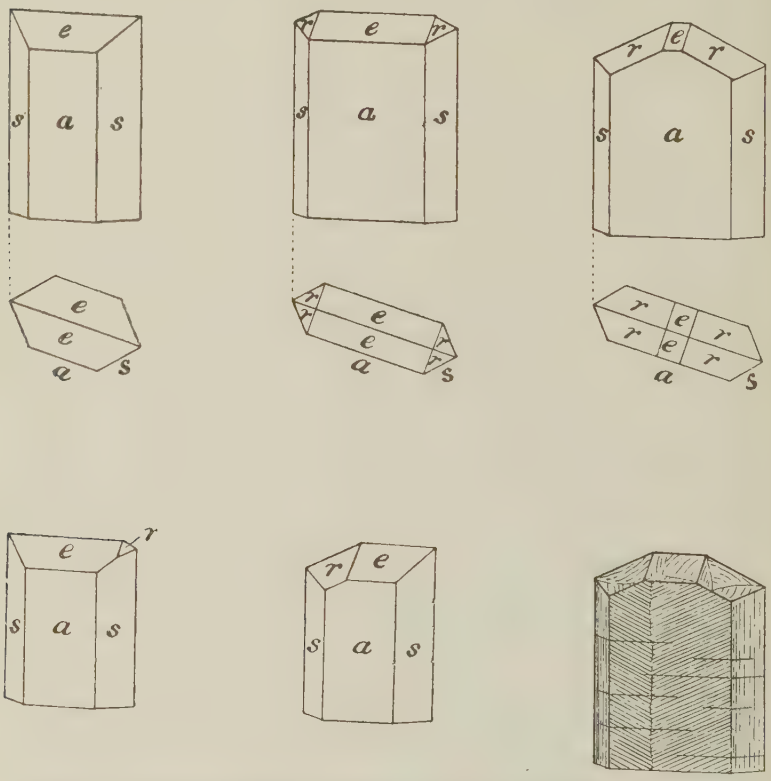

Fig. 1.—Crystals of hopeite from Broken Hill, North-Western Rhodesia. (Clinographic drawings and plans.)

The crystals are represented as terminated below by the basal cleavage. Two of the lower figures show the irregular development of the crystals, owing to the omission of pyramid-planes; another shows the surface characters of the faces and the cleavage cracks parallel to the base.

(see figs.), but there is no regularity in this omission of faces. The crystals are usually attached at one end, though this is not always the case, and doubly terminated crystals are not infrequent. There are no indications of twinning.

Although the crystals are so brilliant and their edges so sharp, they are not suitable for very exact measurements. There is a tendency to a sub-parallel grouping of the crystals, and the faces are striated and show uneven, vicinal growths.

The axial ratios calculated from the mean values of the angles $as = 49° 10'$ and $ae = 50° 34'$, measured on fourteen crystals, are:—

$$a : b : c = 0{\cdot}5786 : 1 : 0{\cdot}4758.$$

These values are compared below with those obtained by previous observers:—

	a : b : c	$as =$ (100) : (120).	$ae =$ (100) : (101).
Haidinger (1824)	0·5796 : 1 : 0·4744	49° 13′	50° 42′
Lévy (1843)	0·5723 : 1 : 0·4718	48 51	50 30
Cesàro (1898)	0·5866 : 1 : 0·4838	49 33½	50 29
Schulten (1904)	0·5759 : 1 : 0·4759	49 2	50 26

The new values are thus closer to the values calculated from Haidinger's early measurements and those of de Schulten for artificial crystals, than to the usually accepted values of Lévy.

The following table gives the measured and calculated angles:—

	Calculated.	Measured.	Limits.	No.
as = (100) : (120)	—	*49° 10′	48° 47′ — 49° 44′	22
ss' = (120) : ($\bar{1}$20)	81° 40′	81 41	80 5 — 82	10
sb = (120) : (010)	40 50	40 47	40 15 — 40 59	5
ai = (100) : (5.11.0)	51 51	51½	51 5 — 52	4
an = (100) : (130)	60 3	60	59½ — 60½	7
ae = (100) : (101)	—	*50 34	49 48 — 51 14	31
ee' = (101) : ($\bar{1}$01)	78 54	78 51	78 13 — 79 10	17
eu = (101) : (103)	24 7	22¾	19 — 24	12
uu' = (103) : ($\bar{1}$03)	30 40	31½	31 — 33	5
ar = (100) : (111)	53 24	53 24	53 3 — 53 34	13
rr' = (111) : ($\bar{1}$11)	73 12	73 17	72 9 — 74 56	12
rf = (111) : (011)	36 36	36 42	36½ — 37	8
re = (111) : (101)	20 11	20 0	19 48 — 20 11	8

The considerable variations in the readings recorded above are to be accounted for by the vicinal character of many of the faces. Some of the best readings between faces giving single sharp images are: $ee' = 78° 42'$, 78° 48′; $rr' = 73° 10'$, 73° 15′; $re = 20° 11'$, 20° 9′, which agree more closely with the calculated values.

The characters of the faces of the forms observed are :—

a {100}. The largest plane on the crystals, parallel to which they are usually tabular in habit. It often gives scattered images, owing to the sub-parallel grouping and to vicinal faces. Striations arranged in a herring-bone pattern are sometimes present (fig. 1). The lustre on this plane is pearly, owing to the perfect cleavage in this direction.

s {120}. The predominating prism. Striated vertically.

i {5.11.0}. Observed on only one crystal as four faces quite distinct from *s*, but inclined to it at only about 2°. Striated vertically.

n {130}. Usually quite narrow : striated vertically. Observed on four crystals.

b {010}. Rarely present, as a narrow face.

e {101}. Largely developed on all crystals. Usually reflects two images at from 3′ to 21′ apart in the zone [100, 001]. Sometimes corroded, and with a surface like ground-glass.

u {103}. Usually as very narrow planes rounded in the zone [100, 001] and reflecting a faint band of images. Only on one of the fourteen measured crystals were these planes of any appreciable size.

f {011}. As narrow planes truncating the edges [*rr*′].

r {111}. Present on most crystals, though not invariably. The faces often show uneven growths and vicinal faces (see fig. 1), and they rarely give single reflected images. The multiple images lie in the zone [*a r*]=[100, 111], and between the outside images of each group the following angles were measured : 12′, 17′, 19′, 54′, 2° 46′. Sometimes the faces are roughened like ground-glass.

q {233}. As a very narrow plane, together with {011} and {133}, on an edge [*rr*′] of one crystal. Measured to *r* 10½°. (Calculated, 10° 16′.)

t {133}. Ditto. Measured to *r* 23°. (Calculated 22° 42′.)

Crystal-forms of Hopeite.

Forms.		Haidinger, 1824.	Lévy, 1837.	Lévy, 1843.	Des Cloizeaux, 1879.	Friedel and Sarasin, 1879. (On artificial crystals.)	Cesàro, 1898.	Schulten, 1904. (On artificial crystals.)	Buttgenbach, 1906.	Spencer. (On Rhodesian crystals.)
Pinacoids.	$a\{100\}$	d	h^1	h^1	h^1	h^1	h^1	h^1	h^1	a
	$b\{010\}$	e	g^1	g^1	g^1	g^1	g^1	g^1	g^1	b
	$c\{001\}$	×	—	—	p	p	—	—	—	—
Prisms.	$y\{310\}$?	—	h^2	—	—	—	—	—	—	—
	$x\{320\}$	—	—	h^5	—	—	—	—	—	—
	$m\{110\}$	—	m	m	—	m	—	—	—	—
	$s\{120\}$	b	—	g^3	g^3	—	g^3	g^3	g^3	s
	$i\{5.11.0\}$	—	—	—	—	—	—	—	—	i
	$n\{130\}$	—	—	g^2	—	—	—	g^2	g^2	n
	$k\{160\}$	—	—	—	—	—	—	$g^{\frac{1}{6}}$	—	—
Brachy-Macrodomes.	$d\{201\}$?	—	a^1	—	—	—	—	—	—	—
	$e\{101\}$	a	a^1	a^2	a^1	—	a^1	a^1	a^1	e
	$u\{103\}$	—	—	a^6	a^3	a^3	a^3	a^3	a^3	u
Brachy-dome.	$f\{011\}$	—	—	—	—	—	—	e^1	—	f
Pyramids.	$r\{111\}$	c	b^1	b^1	$b^{\frac{1}{2}}$	—	$b^{\frac{1}{2}}$	—	$b^{\frac{1}{2}}$	r
	$q\{233\}$	—	—	—	—	—	—	—	—	q
	$t\{133\}$	—	—	—	—	—	—	—	—	t

From this table it will be seen that the common forms of hopeite recorded by almost all observers are only *a b s e u r*. The forms *y* {310} and *d* {201} given by Lévy in 1837 are not included in his list published in 1843; and it is possible that they were given in error for the common forms *s* and *u* respectively, but their position as {310} and {201} is clearly indicated on his earlier figure.

Cleavage.—Hopeite possesses three directions of cleavage parallel to

the three axial planes, and the crystals can be broken up into cubical blocks.

a (100) is the direction of the most perfect cleavage, and on this plane the lustre is pearly ; on other faces the lustre is vitreous.

b (010) is a direction of good cleavage, which can be readily developed by placing a knife-edge in the proper direction on a crystal and striking a sharp blow with a hammer. Cleavage-flakes so obtained have smooth, glassy surfaces, and, being perpendicular to the acute optic bisectrix, enable the peculiar optical characters of the mineral to be easily studied. The crystals rarely show any cleavage cracks in this direction, and unless this cleavage is intentionally developed it is not readily noticed.

c (001) is a direction of poor cleavage, but it is a prominent feature in almost all crystals by reason of cleavage cracks (as represented in fig. 1); the cleavage surfaces are not very smooth.

Hardness.—This may be given as $3\frac{1}{4}$, since the mineral is more easily scratched by fluorite than is calcite by hopeite. The crystals seem to be rather less hard on the pearly *a* cleavage than on the other faces. The hardness as given in the textbooks is clearly too low ; A. de Schulten (1904) gives the value for artificial crystals as a little greater than 3.

Specific Gravity.—Here again the values given in the textbooks are much too low. Brewster (1824) obtained for a single, presumably quite small, crystal the value 2·76, and Lévy (1843) found for three small crystals, weighing together only 10 milligrams, 2·85. A. de Schulten determined for artificial crystals 3·109.

For the Rhodesian crystals I have determined the following values :—

3·08, a large white crystal, measuring 2 cm. across and weighing 2·795 grams; by hydrostatic weighing.

3·06, large white crystals, weighing together 1·989 gram; with a 3 cc. pycnometer.

3·04, small, clear, glassy crystals, weighing together 0·699 gram; ditto.

By floating a large number of small, isolated crystals in methylene iodide, with indicators of rubellite and spodumene, the specific gravity of the different crystals was found to vary from about 3·0 to 3·1.

As will be described below, the crystals of hopeite consist of a zonal intergrowth of two substances, which differ slightly in specific gravity. With the idea of separating these two modifications of hopeite, 5·6 grams of the large white crystals were crushed to a coarse powder, and the heaviest and lightest fractions separated by means of methylene iodide. The separation was, however, far from complete, as was easily seen on an

optical examination of the fragments of the two lots. The results obtained with the pycnometer were :—

3·04 for the specifically heaviest portion, weighing 1·035 gram.

3·03 for the specifically lightest portion, weighing 1·851 gram.

Optical Characters.—Although some remarkable features are presented by the optical characters of hopeite, yet these are in complete accord with the orthorhombic symmetry of the crystals. On all faces the extinction is uniform and parallel to the crystallographic axes. A cleavage-flake parallel to the brachypinacoid $b\{010\}$, perpendicular to which is the acute bisectrix of the optic axes, exhibits, even in ordinary light, a zonal structure, the numerous lamellae being arranged parallel to the faces of the dome $e\{101\}$ and of the macropinacoid $a\{100\}$ (fig. 2). This zonal structure is shown most conspicuously when the cleavage-flake is viewed between crossed nicols, since the lamellae polarize alternately in bright colours and in low grey tints. These lamellae are extremely numerous, varying in width from about $\frac{1}{100}$ to $\frac{1}{2}$ mm.; the two sets extinguish simultaneously when the vibration-directions of the nicols are parallel to the a and c edges of the plate. These lamellae mark out the stages of growth of the crystal; sometimes the bands are rather crumpled, or they bear on their upper edges small tufts parallel to the c-axis of the crystal. On no other face of the crystal, nor on a- or c-cleavage-plates, is there the slightest indication of this compound structure.

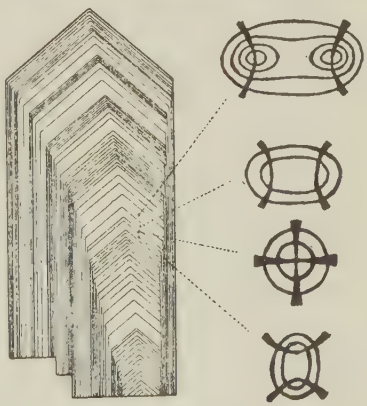

Fig. 2.—Hopeite : cleavage-flake parallel to the brachypinacoid, $b\{010\}$, showing zonal interbanding of α-hopeite and β-hopeite, and the interference-figures given by different bands.

In convergent light between crossed nicols a remarkable series of changes in the interference-figure is seen as the b-section is moved across the stage of the microscope. The figure continuously and rapidly changes from one with a wide axial angle and several brightly coloured rings, to one with a smaller axial angle and few rings less brightly coloured, and vice versa: further, the plane of the optic axes also changes into positions at right angles, and at certain points the figure is uniaxial. These interference-figures are often considerably distorted; e. g., rings

without brushes may be often seen. This is, however, due to the combined effect of two or more of the very narrow lamellae: when a wider band is under observation, the figure is perfectly normal. The optic sign of these interference-figures is in all cases negative, and the acute bisectrices are perpendicular to the plane of the plate.

It will be convenient to distinguish the material of which these two sets of lamellae are composed as α-hopeite and β-hopeite respectively. The main optical differences between them may be summarized as follows:—

α-Hopeite.—Higher birefringence, polarizing in bright colours. Acute, negative bisectrix perpendicular to *b* (010), and optic axial plane parallel to *c* (001). Wider optic axial angle (2E about $58\frac{1}{2}^\circ$), and the interference-figure with several brightly coloured rings.

β-Hopeite.—Much lower birefringence, polarizing in grey tints. Acute, negative bisectrix perpendicular to *b* (010); optic axial plane sometimes parallel to and sometimes perpendicular to *c* (001). Narrower angle between the optic axes (2E about $32\frac{1}{2}^\circ$ when the axial plane is parallel to *c* (100), and 2E about 20° when perpendicular thereto), and the interference-figures with very few, less brightly coloured rings.

The uniaxial interference-figures with low birefringence shown by some portions of the bands of β-hopeite, are doubtless due to the overlapping of two biaxial portions the optic axial planes of which are at right angles.

These two orthorhombic modifications of hopeite differ also in some other respects. When a *b*-section is gently warmed or when boiled in water, there is no change in the optical characters, but at a temperature of 105° C. the α-hopeite is destroyed and no longer shows any of the optical characters above described, either in parallel or in convergent polarized light. A plate which has been heated to this temperature shows, even to the naked eye, alternate bands of opaque, white material, and of clear, transparent material, the latter being the unaltered β-hopeite. The opacity of the bands of altered α-hopeite is seen, under the microscope, to be due to the presence of vast numbers of minute spindle-shaped bodies closely arranged side by side parallel to the vertical *c*-axis of the crystal, and extending completely across each band. On placing the section in water there was no return to the original optical conditions; so that in this respect, as also in the absence of any progressive change in the optical characters with change of temperature, hopeite behaves quite differently from the zeolites.

When heated to a temperature of 110° C. the bands of β-hopeite still show the characteristic figures in convergent light, though now perhaps

the axial angle is rather smaller than before, and the birefringence seems also to be less. The plate is now much cracked along cleavages parallel to c (001). Cleavage-flakes parallel to a (100), after being heated to this temperature, still show bright polarization-colours in parallel light. At 139° C. the b-section becomes wholly opaque, and no longer shows the optical characters of β-hopeite. A cleavage-flake parallel to a (100) is, however, still doubly refracting with uniform and straight extinction; and the same was observed in flakes that had been heated even to redness.

There is thus an appreciable difference in the temperature at which water is expelled from α-hopeite and from β-hopeite (see p. 17). There also appears to be a slight difference in their solubility in acid. After a b-section of a crystal of hopeite has been immersed for a short time in a drop of dilute hydrochloric acid the zonal structure may be seen somewhat more distinctly under a hand magnifying lens.

In specific gravity there was also found to be a slight difference between α-hopeite and β-hopeite. On breaking up a b-section and selecting fragments in which one or other modification predominated, it was found that in methylene iodide the fragments in which β-hopeite predominated were lighter than pale-rose tourmaline from Elba (sp. gr. 3·02), and that those in which α-hopeite predominated sank while the tourmaline floated (see p. 10).

An analogous case of the regular intergrowth of two modifications of the same substance is that of zoisite described by P. Termier[1], who distinguishes α-zoisite and β-zoisite by differences in optical characters.

Since all the crystals of hopeite consist of two substances intimately intergrown, and differing widely in their optical characters, it is not possible to make any exact determinations of the optical constants. The values obtained are not concordant, for they result from the combined effect of the two modifications in varying proportions.

Numerous determinations of the *refractive indices* were made by the method of minimum deviation through prisms formed by the natural faces of the crystals. On one crystal, for example, the four prisms formed by the faces of the forms a {100} and s {120}, with refracting angles varying between 48° 58′ and 49° 26′ gave, for sodium-light :—

> 1·593 (mean of 1·5937, 1·5915, 1·5930, 1·5928) for vibrations parallel to the vertical c-axis of the crystal (i.e. the combined effect of the β index of α-hopeite and of the β or γ index of β-hopeite).

[1] P. Termier, Bull. Soc. franç. Min., 1898, vol. xxi, p. 148 ; 1900, vol. xxiii, p. 50 ; abstracts in Min. Mag., vol. xii, p. 215, vol. xiii, p. 207.

1·585 (mean of 1·5862, 1·5843, 1·5829, 1·5856) for vibrations perpendicular to the *c*-axis (i. e. the combined effect of the α and γ indices of α-hopeite and of the α and γ or α and β indices of β-hopeite).

With the same crystal the refractive indices determined through the two prisms formed by the faces of the forms a {100} and e {101}, with refracting angles of 50° 6′ and 50° 52′, were, for sodium-light:—

1·5903 and 1·6022, for vibrations parallel to the *b*-axis of the crystal (i.e. the combined effect of the α index of α-hopeite and of the α index of β-hopeite).

1·6024 and 1·6117, for vibrations perpendicular to the *b*-axis (i. e. the combined effect of the β and γ indices of α-hopeite, and of the β and γ indices of β-hopeite).

With a second crystal the corresponding values were :—

Prism *as'*, 1·5893, for vibrations parallel *c*-axis.
1·5816, for vibrations perpendicular *c*-axis.
Prism *ae'*, 1·5806, for vibrations parallel *b*-axis.
1·5902, for vibrations perpendicular *b*-axis.

These results are of little value beyond serving to indicate the mean refractive power of the mineral. They are in agreement with Brewster's determination (1824) of 1·601 for the ordinary index measured through the prism *ae'*. The value $\beta = 1{\cdot}471$ calculated by Des Cloizeaux (1879) from his measurements of the optic axial angles is clearly too low, whilst the approximate value of 1·666 determined by H. Buttgenbach (1906) by the Duc de Chaulnes's method is too high.

The measurements obtained for the value of the *optic axial angle* are also unsatisfactory; for, as the section is rotated, different lamellae may come into coincidence with the axis of the instrument. No dispersion of the optic axes could be detected or measured.

For α-hopeite the following values were determined for the angle in air:—

$2\,E = 55\frac{1}{2}°$, $58\frac{1}{2}°$ (with the axial angle apparatus in sodium-light).
58°, $60\frac{1}{2}°$, $63\frac{3}{4}°$ (with the microscope stage-goniometer).
50°–$57\frac{1}{2}°$ (with a micrometer-scale in the eye-piece of the microscope).

For β-hopeite when the optic axial plane is parallel to *c* (001):—

$2\,E = 30\frac{3}{4}°$, $32\frac{1}{2}$ (axial angle apparatus in sodium-light).
$27\frac{1}{2}°$ (stage-goniometer).
24°, $32\frac{1}{2}°$ (micrometer-scale).

For β-hopeite when the optic axial plane is perpendicular to c (001):—
$2E = 18°, 23°$ (micrometer-scale).

Determinations of the angle in cedar oil ($n = 1.516$) gave:—

for α-hopeite, $2H_a = 35\frac{1}{2}°, 36\frac{1}{2}°, 37°$ (Na).
for β-hopeite, $2H_a = 21\frac{1}{2}°–23\frac{3}{4}$ (Na).

Attempts to measure the obtuse angle between the optic axes through a cleavage-plate parallel to a (100) were made in cedar oil and methylene iodide, but without success, for the axes do not emerge. Through the prism-faces of s {120} two sets of rings, but without brushes, were visible, and gave in cedar oil $2H_a = 43°$ and $33°$ respectively; but these results are not concordant with the other values.

Assuming the β index of hopeite to be 1·59, the axial angles in the crystal are calculated as:—

for α-hopeite, $2V = 36°$ about.
for β-hopeite, $2V = 20°$ about.

As is also the case with the refractive index, my determinations of the optic axial angle of hopeite are in closer agreement with the value obtained by Brewster (namely 48°), than with those of Des Cloizeaux ($2E = 78° 35'$, $2V = 54° 44'$, Na) and Buttgenbach [1] ($2E = 149° 32'$, $2V = 70° 47'$).

Des Cloizeaux mentions that the interference-figures are distorted, and he suggests that the distortion is due to twin-lamellae. This suggests that the original hopeite from Altenberg also presents the same lamellar intergrowth as the Rhodesian crystals, but the former I have not been able to examine optically.[2]

Friedel and Sarasin (1879), and de Schulten (1904), say of the artificial crystals that in optical characters they agree with the natural mineral (as previously determined by Des Cloizeaux); they give the optic axial plane as being parallel to c (001). Crystals of hopeite are readily deposited from a solution of zinc phosphate in acetic acid. The crystals which I so obtained are pearly scales flattened parallel to a (100) and with a rectangular outline; they are about $\frac{1}{4}$ mm. in length, and between crossed nicols extinguish parallel to their edges. As these artificial crystals are not flattened parallel to b (010) it is not possible to say whether or not they consist of zonal intergrowths as do the natural Rhodesian crystals.

[1] Buttgenbach's determination was made under the microscope through the prism s and is clearly of no value.

[2] The single specimen of hopeite from Altenberg in the British Museum collection shows only four minute crystals.

Etching.—A cleavage-flake parallel to *a* (100) of hopeite is quickly attacked in even very dilute hydrochloric acid, and the surface becomes dull. Under the microscope, the etched surface shows a shagreen appearance, with no very well-marked corrosion-figures. Under a high power, however, minute six-sided elevations are to be seen; these have their edges parallel to the brachypinacoid and the four adjacent pyramid-planes. The crystals therefore possess holohedral-orthorhombic symmetry.

On a cleavage-flake parallel to *b* (010) the action of the acid is less rapid, and is mostly shown by a rounding of the sides of the flake, due to the more rapid solution on the *a* and *c* faces. No well-marked corrosion-figures were seen, only a few long bars parallel to the vertical *c*-axis and running across the bands of *α*-hopeite and *β*-hopeite. After a *b*-cleavage-flake has been in the acid, the zonal banding is rather more readily seen in ordinary light, indicating that the two constituents have been dissolved in slightly different amounts.

No electrical charge could be detected on crystals of hopeite while they were cooling; the mineral is therefore not pyro-electric.

Chemical Composition.—Owing to the very sparing occurrence of the mineral at the original locality, natural crystals of hopeite have not hitherto been analysed quantitatively. Several analyses have been made, by H. Debray (1861), W. Heintz (1867), C. Friedel and E. Sarasin (1879), and A. de Schulten (1904), of artificial crystals, and these give the formula $Zn_3P_2O_8.4H_2O$.

Heated in a bulb-tube, a crystal of hopeite readily gives off abundance of water. The crystal is then white (both when hot and when cold; compare tarbuttite, p. 27) and opaque with a porcellanous aspect. Before the blowpipe, on a loop of platinum wire, the material readily fuses to a clear, colourless bead, and imparts a pale greenish coloration to the flame. As the bead cools, spherulitic growths rapidly spread over the surface and the bead consolidates partly as crystallized (birefringent) material and partly as a clear, colourless (isotropic) glass. On the final consolidation of a large bead, molten material is violently erupted from the interior to the surface where it consolidates as a glass, leaving pits resembling the craters of volcanoes.

Hopeite is readily soluble in dilute hydrochloric acid. In this solution ammonia produces a bulky white precipitate which is soluble in excess of ammonia, though apparently not so readily as in the case of parahopeite and tarbuttite. Qualitative tests showed the presence of only zinc, phosphoric acid, and water: cadmium was not detected.

A separation of the α-hopeite and the β-hopeite was attempted by crushing 5·6 grams of the large white crystals to a coarse powder and placing in methylene iodide (p. 10). The heaviest (sp. gr. 3·04) and lightest (sp. gr. 3·03) fractions were, however, far from consisting wholly of α-hopeite and β-hopeite respectively, but in the following determinations it will be convenient to refer to them as such.

About a gram of each fraction was taken, and they were heated side by side in an air-oven for one hour at different temperatures. The percentage losses of weight are given below and are also plotted in fig. 3.

	114°	135°	150°	180°	203°	221°	240°	290°C.	Red-heat.
α-hopeite ...	5·2	8·5	9·2	9·8	10·1	11·8	14·9	15·8	16·1 % H_2O.
β-hopeite ...	2·5	7·9	10·9	11·1	11·7	12·0	13·3	15·8	16·2 % H_2O.

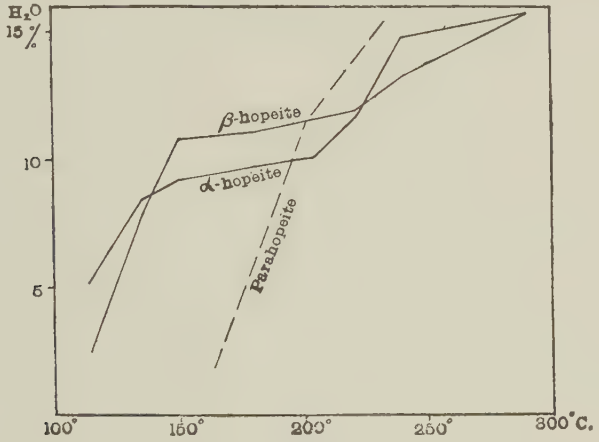

Fig. 8.—Curves representing the rate of loss of water with rise of temperature from α-hopeite, β-hopeite, and parahopeite.

These results show that there is an appreciable difference between α-hopeite and β-hopeite in respect to the temperature at which the water is expelled. The much greater loss from α-hopeite at 114° C. is in agreement with observations made when a section of a crystal perpendicular to the acute optic bisectrix was heated (p. 12).

As may be seen from fig. 3, about half of the water is expelled at 135° C.; and there is much less loss between 135° C. and 221° C. than below and above these points. Other determinations of the loss on ignition were 16·1 and 16·2 per cent., made respectively on 1·990 and 1·108 gram of the large white crystals.

In the quantitative analysis of the two separated portions, the material,

after ignition, was fused in a platinum crucible with sodium carbonate, and the melt extracted with boiling water; the residue, after ignition, was weighed as zinc oxide; and from the filtrate, phosphoric acid was precipitated with magnesia mixture and weighed as magnesium pyrophosphate. The following results were obtained:—

	α-Hopeite.	β-Hopeite.	Calculated for $Zn_3P_2O_8.4H_2O$.
ZnO ...	52·1	51·9	53·3
P_2O_5 ...	31·8	[31·9][1]	31·0
H_2O ...	16·1	16·2	15·7
	100·0	100·0	100·0
Sp. gr. ...	3·04	3·03	—

The above analyses show that there is no difference in composition between α-hopeite and β-hopeite. Both of them agree closely enough with the formula $Zn_3P_2O_8.4H_2O$ or $3ZnO.P_2O_5.4H_2O$; but, like almost all analyses of artificial hopeite, they show slight variations from the theoretical values. The same differences are not shown in the analysis of parahopeite (p. 21), and, as remarked above, there appears to be a difference in the solubility in ammonia of the zinc phosphate from hopeite and that from parahopeite. In the case of zinc and phosphoric acid it is possible that these differences may be partly due to imperfect separation, but not so with the water. The same slight excess of water was observed by W. Heintz (1867) and by C. Friedel and E. Sarasin (1879) for artificial hopeite; the former suggested that it might be due to an admixture of an acid salt $H_2Zn_2P_2O_8.3H_2O$ with the normal salt $Zn_3P_2O_8.4H_2O$ in the proportion of one molecule of the former with four of the latter.

Since α-hopeite and β-hopeite differ neither in chemical composition nor in crystalline form, they cannot be considered as dimorphous modifications in the same sense that hopeite and parahopeite are dimorphous.

Parahopeite.

This name[2] I propose to give to a new species of hydrous zinc phosphate, identical with hopeite in chemical composition, but differing from both α-hopeite and β-hopeite in physical and crystallographic characters.

In external appearance, the new mineral has little in common with hopeite, and, at first sight, it has a striking resemblance to the hydrous

[1] By difference: the zinc oxide was tested and found to be free from phosphoric acid.

[2] The name parahopeite appeared in the report of the Mineralogical Society's meeting of November 12, 1907, as given in 'Nature', 1907, vol. lxxvii, p. 143.

zinc silicate, hemimorphite. I have been able to find only two specimens on which this mineral is prominently developed, though small, inconspicuous crystals of parahopeite were detected on a few specimens of pseudomorphous tarbuttite (p. 29). On one of the two specimens the platy crystals of parahopeite are thickly grouped together on a layer of colourless tarbuttite crystals, which rest on dark-brown, cellular limonite. On the other specimen the thin, platy crystals are clustered in tufts on nodular, ochreous limonite; on the back of the specimen are a few minute crystals of pyromorphite.

The crystals of parahopeite are colourless and transparent with a vitreous lustre, and have the form of thin plates arranged in divergent or fan-shaped groups. In size they measure 3 to 5 mm. across.

Crystalline Form.—The crystals are so deeply striated and bunched together with sub-parallel grouping that it is impossible to determine even approximately their crystallographic constants. The appearance of the crystals is approximately represented in the accompanying figure (fig. 4). The faces lettered *d* and *d'* are, however, not so definite as represented in the figure, but are merely seen as numerous small spots on the edges and corners of the crystals; on the goniometer these give, like all the other faces of the crystals, a whole field full of scattered images. Attempts were made to measure eight crystals, which were selected from a large number of crystals detached from the specimens; and the following angles may be given, but they are of little value :—

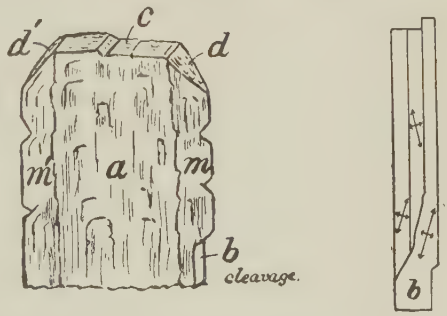

Fig. 4.—Parahopeite crystal: on the right a cleavage-flake parallel to *b* (010), showing the directions of optical extinction.

ab or $a'b$ = 88° – 94°.
am ,, am' = 33° – 37°, 42°.
ac ,, $a'c$ = 85° – 92°.
bc ,, $b'c$ = 86° – 95°.
bd ,, $b'd'$ = 22°, 34°, 44°, 57°, 66°, 73°.

There is a direction of perfect cleavage, on which the lustre is somewhat pearly, parallel to *b*, i.e. perpendicular, or nearly so, to the large plane *a*, and parallel to the length of the crystal and to the striations on

a. The cleavage-planes are usually sharply divided parallel to their length into two or more strips, which are inclined to one another at small re-entrant or salient angles. Each of these long, narrow areas gives a single, sharp reflected image, and the angles between them were measured, in the zone [*ab*], as: 52′, 3° 33′, 4°, 5° 19′, 6°, 6½°. The appearance is quite like that shown on the basal (*c*) cleavage of albite-twins of plagioclase-felspar. That parahopeite may be anorthic and twinned like albite is also suggested by the optical characters. It must, however, be noted that the crystals are arranged in fan-shaped aggregates with the edges [*ab*] of the several individuals approximately parallel, and this may partly account for the small re-entrant and salient angles measured on the *b*-cleavage.

Optical Characters.—On the large plane *a* the crystals polarize in bright colours, whilst on *b* the double refraction is much lower. The angle of extinction on *a* is 30° with reference to the edge [*ab*]. Through *a*, in convergent light with a $\frac{1}{2}$-inch objective in oil, a somewhat indistinct obtuse bisectrix was noted. Cleavage-flakes parallel to *b* show, in parallel light between crossed nicols, quite the appearance of a cleavage-flake of albite twinned according to the albite-law. Two or several lamellae may be seen, and these have different directions of extinction, but alternate lamellae extinguish simultaneously (fig. 4). The extinction-angles measured on *b* with reference to the edge [*ab*] vary widely—0°, 8°, 14°, 20°. 25°. In convergent light through *b* is seen a series of coloured rings and a brush around one of the optic axes of a biaxial interference-figure. This is quite near the centre of the field, and has about the same position in different lamellae, though the direction of the optic axial plane varies. The sign of the double refraction is positive. Up to 163° C. there is no noticeable change in the optical characters of parahopeite, though at this temperature the crystals commence to become white and opaque.

A determination of the refractive index, kindly made by Dr. G. F. Herbert Smith with his new model of refractometer, gave the value 1·62 for sodium-light.

Specific Gravity and Hardness.—The crystals just float in pure methylene iodide. With the pycnometer, 0·889 gram of crystals gave the value 3·31.

The hardness may be placed at 3¾; the crystals easily scratch calcite, and they also are capable of scratching hopeite.

Chemical composition.—Qualitative tests showed the presence of only zinc, phosphoric acid, and water; cadmium was not detected. The behaviour of parahopeite when heated in a bulb-tube, or before the blow-

pipe on a loop of platinum wire, is exactly like that of hopeite (p. 16). The mineral is readily soluble in dilute hydrochloric acid.

A quantitative analysis [1] was made on 0·885 gram, with the following results :—

	Found.	Calculated for $Zn_3P_2O_8.4H_2O$.
ZnO . . .	53·0 . . .	53·3
P_2O_5 . . .	31·6 . . .	31·0
H_2O . . .	15·6 . . .	15·7
	100·2	100·0
Sp. gr. . .	3·31 . . .	—

Another determination of the water (loss on ignition), made on 0·309 gram, gave 15·8 per cent.

In determining the rate of loss of water with increasing temperature, the behaviour of parahopeite was compared with that of hopeite, the two minerals being heated side by side in an air-oven. The following were the percentage losses of weight during one hour at the different temperatures :—

	113°	139°	163°	201°	233° C.	Red-heat.
Parahopeite ...	nil	nil	1·9	11·6	15·5	15·8 % H_2O
Hopeite ...	1·6	9·2	10·1	10·6	13·5	16·2 % H_2O

The results for parahopeite are plotted in fig. 3 (p. 17), and they show a striking difference in the behaviour of the two minerals.

Comparison of the characters of parahopeite and hopeite.

	Parahopeite.	Hopeite.
Colour . . .	Colourless, transparent.	Colourless, transparent.
Lustre . . .	Vitreous, somewhat pearly on the cleavage.	Vitreous, strongly pearly on the *a* cleavage.
Crystal-system . .	Anorthic.	Orthorhombic.
Cleavage . . .	*b* perfect.	*a* perfect, *b* good, *c* poor.
Optical character .	Biaxial, positive.	Biaxial, negative.
Refractive indices .	1·62	1·58–1·60
Hardness . . .	$3\frac{3}{4}$	$3\frac{1}{4}$
Specific gravity . .	3·31	3·0–3·1
Chemical composition .	$Zn_3P_2O_8.4H_2O$	$Zn_3P_2O_8.4H_2O$
Loss of water at 139°C.	nil.	9·2 per cent.
„ „ 233°C.	15·5 per cent.	13·5 „

In this analysis, the water was determined as the loss on ignition; zinc was precipitated from the ammonia solution as sulphide and, after repeated ignitions, weighed as oxide; and in the filtrate the phosphoric acid was precipitated with magnesia mixture.

Tarbuttite.

For the basic zinc phosphate to be now described I have proposed the name of tarbuttite,[1] after Mr. Percy Coventry Tarbutt, who himself collected, at the Broken Hill mines in Rhodesia, several of the specimens which he has generously presented to the British Museum.

At this locality tarbuttite is found in great abundance, and large, beautifully crystallized specimens are by no means uncommon. Only rarely is a new mineral species found in such profusion. There is also an extraordinary variety both in the character of the specimens and in the appearance of the tarbuttite itself.

The most distinctly crystallized material occurs as an encrustation on masses of cellular or stalactitic limonite, and is often associated with earlier formed crystals of either descloizite or pyromorphite. On the surface of the tarbuttite crystals there are sometimes a few small (1 mm., or less, across), colourless rosettes of hemimorphite crystals. Minutely crystallized crusts of pseudomorphous tarbuttite (p. 28) are also very abundant. These occurrences are in Kopje No. 2, and are not associated with the hopeite in the bone-cave in Kopje No. 1. Tarbuttite was, however, detected in the very thin and minutely crystallized crusts on the hopeite specimens and on some of the bones from the cave (p. 30).

The crystals of tarbuttite are sometimes perfectly colourless and transparent, and have a brilliant, vitreous lustre on their faces. More usually, they are pale shades of yellow, brown, red, or green, with varying degrees of transparency. The green colour is due to the presence of traces of copper, and the other colours to the inclusion of iron hydroxides in the crystals. In size, the crystals vary from about half a centimetre across down to microscopic dimensions.

As a rule, the crystals are thickly clustered together; but sometimes they occur singly on the matrix or attached to crystals of pyromorphite. In the latter case, when the crystals have only a slight point of attachment (for instance, when perched on the top of a crystal of pyromorphite), they may be completely bounded on all sides by crystal-faces.

Crystalline form.—The crystals (fig. 5), invariably show a tendency, which is sometimes very pronounced, to grow in sheaf-like aggregates; and this gives rise to a frequent repetition of the faces in nearly parallel positions. Further, the faces, especially the larger ones, are deeply

[1] The name tarbuttite first appeared in 'Nature', 1907, vol. lxxvi, p. 215, in the report of the Mineralogical Society's meeting of June 11, 1907; and was also given in my list of new mineral names in Min. Mag., 1907, vol. xiv, p. 411.

striated and are much rounded by irregularities of growth. Some of the smaller faces on the corners of the crystals are perfectly smooth and give single reflected images; but as these small faces are frequently repeated in nearly parallel positions on adjacent portions of the crystal, the measurements from them are confused.

For these reasons only a small number of reliable measurements could be obtained; and the presence of but few well-defined faces in the primary zones on the crystals make the calculations all the more awkward. About a dozen crystals were measured in detail, but the elements given below can only be considered as a first approximation.

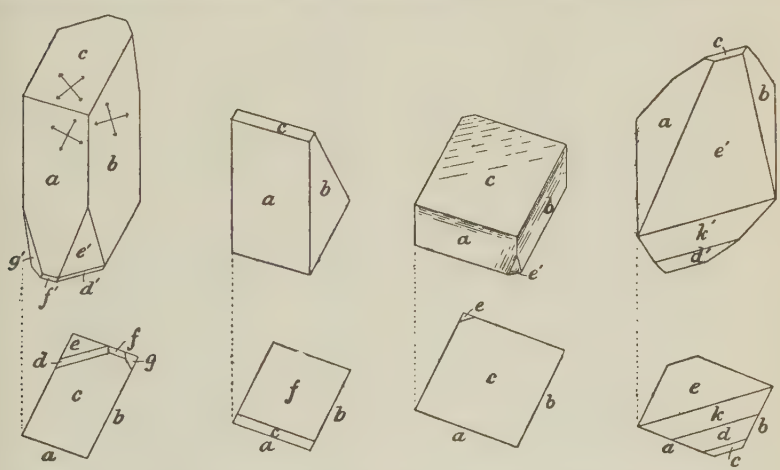

Fig. 5.—Crystals of tarbuttite from Broken Hill, North-Western Rhodesia. (Clinographic drawings and plans.)

The first figure shows the directions of optical extinction on the faces *a*, *b*, *c*. In the second figure the crystal is terminated below by the cleavage parallel to *c* (001). The third figure represents the striations on the faces.

The crystals are anorthic with parallel faces; and the elements (calculated from the angles *ac*, *ab* and *ab'*, *cb* and *cb'*, *cf*, and *cd*) are :—

$$a : b : c = 0{\cdot}9583 : 1 : 1{\cdot}3204 ;$$
$$\alpha = 102^\circ\ 37', \beta = 123^\circ\ 52', \gamma = 87^\circ\ 25'.$$

The forms determined on the crystals are given below in approximately the order of their relative sizes and frequency of occurrence, and their positions are indicated on the accompanying stereographic projection (fig. 6).

$c\{001\}$, $b\{010\}$, $a\{100\}$, $e\{\bar{2}\bar{2}1\}$, $f\{\bar{1}01\}$, $g\{\bar{2}11\}$, $d\}\bar{2}\bar{2}3\}$, $k\{\bar{1}\bar{1}1\}$, $l\{021\}$, $h\{0\bar{2}1\}$, $i\{\bar{1}\bar{2}2\}$, $r\{\bar{2}\bar{4}3\}$, $o\{1\bar{2}1\}$, $s\{\bar{1}02\}$, $t\{\bar{1}03\}$, $u\{0\bar{1}1\}$, $m\{110\}$.

In addition to these, several other forms are present, either as indefinite, striated faces or as minute faces not lying in the zones actually measured.

Measured and calculated angles of tarbuttite.

	Calculated.	Measured.	Limits.	No.
$ac = (100):(001)$	55° 50′	*55° 50′	55° 0′ — 56° 15′	14
$cf = (001):(\bar{1}01)$	77 38	*77 38	77 30 — 77 55	10
$cs = (001):(\bar{1}02)$	42 0	42°	—	1
$ct = (001):(\bar{1}03)$	26 23	26°	25° — 27°	2
$ab = (100):(010)$	84 34	* 84 28	84 30 — 84 52	7
$ab' = (100):(0\bar{1}0)$	95 26	* 95 20	95 4 — 95 32	7
$am = (100):(110)$	37 0	37°	—	1
$cb = (001):(010)$	76 31	* 76 24	75 59 — 77°	8
$cb' = (001):(0\bar{1}0)$	103 29	* 103 15	102 48 — 103 47	4
$ch = (001):(0\bar{2}1)$	77 7	77½°	77° — 77 44	3
$cu = (001):(0\bar{1}1)$	55 7	58°	57° — 58 55	2
$cl = (001):(021)$	54 41	56°	55° — 57½°	2
$cd = (001):(\bar{2}\bar{2}3)$	72 3	*72 3	71 14 — 72 30	10
$ck = (001):(\bar{1}\bar{1}1)$	90 27	90 35	90° — 91°	4
$ce = (001):(\bar{2}\bar{2}1)$	108 45	108 35	108 14 — 109 4	6
$gf = (\bar{2}11):(\bar{1}01)$	43 37	43 59	43 56 — 44 2	4
$fd = (\bar{1}01):(\bar{2}\bar{2}3)$	43 42	44 24	44° — 44 26	4
$di = (\bar{2}\bar{2}3):(\bar{1}\bar{2}2)$	18 34	18 38	18 26 — 18 51	4
$dh = (\bar{2}\bar{2}3):(0\bar{2}1)$	46 1	45 27	45° — 45 58	4

The zones given in the above table of angles are the principal ones on the crystals. Most of the faces were also measured to the three axial planes *a*, *b*, and *c*, and several less important zones might be included in the table. But the calculated and measured angles do not agree as closely as could be wished, and it is unsatisfactory to make tedious calculations when it is clear that the elements are not final. The indices of the remaining faces were determined by the intersection of zones, and the measured angles were checked on the projection with the aid of Penfield's stereographic protractors.

It will be noticed from the above table of angles of tarbuttite that

there is a certain repetition of nearly the same angles in different zones (e. g., *cb*, *cf*, and *ch* about 77°; *a'f* and the angles in the zone [*gh*] about 45°). There is also often an approach in the angles to those of cubic crystals.

In the habit of the tarbuttite crystals there is considerable variation. Some of the more usual forms of crystals are represented in the accompanying figures (fig. 5). Perhaps the most common habit is that shown on the left in fig. 5, where *a* {100}, *b* {010}, and *c* {001} are all large, giving a distorted brick-like shape with small planes on some of the edges and corners.

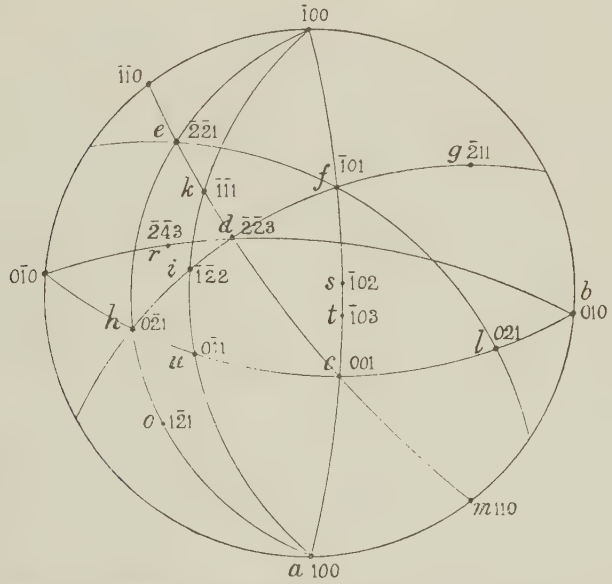

Fig. 6.—Stereographic projection of the crystal-forms of tarbuttite.

Cleavage.—An important feature of tarbuttite is the perfect cleavage parallel to *c* (001). On the cleavage surfaces the lustre is distinctly pearly, though this lustre is often not conspicuous on an uncleaved crystal. The presence of this cleavage helps considerably in the orientation of the crystals, and also in their optical determination. The form *c* {001} is usually prominently developed on the crystals, though sometimes these faces are quite small or altogether absent.

Optical characters.—The directions of optical extinction are oblique on all the faces of the crystals:—

On c (001) at 33° to the edge $[ca]$.
„ „ 35° „ „ $[cb]$
„ „ 10° „ „ $[ce]$.
On b (010) „ 25° „ „ $[bc]$.
„ „ 10° „ „ $[ba]$.
On a (100) „ 26° „ „ $[ab]$.
„ „ 14° „ „ $[ac]$.

These extinction directions are shown in fig. 5; the angles are related to the axial angles as follows:—

On c (001) . . . $33° + (90° - 35°) = 88° = \gamma$.
On b (010) . . . $10° + 25° + 90° = 125° = \beta$.
On a (100) . . . $26° + (90° - 14°) = 102° = \alpha$.

The acute, negative bisectrix of the optic axes emerges obliquely through the perfect cleavage c(001). The interference-figure in convergent polarized light appears on the edge of the field of view, and is best seen with a $\frac{1}{12}$-inch objective in oil. The double refraction is strong, and even a thin cleavage-flake shows several coloured rings; with a thick flake the rings are very small and close together, so that the figure is less readily seen. The trace of the optic axial plane on c (001) is inclined at 33° to the edge $[ca]$, and the acute bisectrix is inclined at an angle of about 40° (in air) to the normal to c (001) towards the face g ($\bar{2}11$). By grinding off the corner formed by the three faces a' ($\bar{1}00$), b (010), and c (001) and the opposite corner of a crystal, a plate was obtained which showed the interference-figure near the centre of the field of view. The axial angle, as approximately measured with the eye-piece micrometer, is about 80° or 90° in air.

The following refractive indices for sodium-light were determined by the method of minimum deviation through prisms formed by the natural faces of the crystals. These are, of course, not the principal indices:—

1·706, 1·665 } through a prism of 46° 24′ formed by the faces a (100) and f ($\bar{1}01$).
1·703, 1·672 } through a prism of 56° 0′ formed by the faces a' ($\bar{1}00$) and c (001).

The double refraction is therefore strong.

The sheaf-like aggregation, especially marked in the larger crystals, precluded any possibility of cutting orientated plates and prisms for the exact determination of the optical constants of the mineral.

Specific gravity and hardness.—Crystals of tarbuttite readily scratch calcite and hopeite; the hardness may therefore be placed as $3\frac{3}{4}$. The mineral sinks in methylene iodide. Determinations of the specific gravity made with the pycnometer gave the following values:—

4·12, on 1·439 gram of pale greenish material forming a crystallized crust, but quite free from impurity.

4·12, on 1·308 gram of similar material from another specimen.

4·15, on 0·847 gram of colourless, transparent crystals associated with pyromorphite (which may account for this slightly higher value).

Chemical composition.—When heated in a bulb-tube, tarbuttite behaves quite differently from hopeite and parahopeite. At a high temperature it decrepitates slightly and gives off only a small amount of water. The material, when hot, is of a bright yellow colour, which changes to pure white on cooling; the crystals are then opaque with a porcellanous appearance. This change in colour indicates that there is a separation of zinc oxide, and that tarbuttite is a basic zinc salt. Heated before the blowpipe on a loop of platinum wire, the mineral readily fuses to a clear, yellow bead, which on cooling crystallizes to an opaque, dark-grey bead; fragments of this are doubly refracting.

The mineral is readily soluble in dilute hydrochloric acid, and from this solution ammonia produces a bulky white precipitate which is readily soluble in excess of ammonia. Qualitative tests proved the presence of only zinc, phosphoric acid, and water; cadmium is absent.

A quantitative analysis was made on 1·308 gram of the pale greenish crystalline material, which, after ignition, was fused with sodium carbonate (as described on p. 18). The following results were obtained:—

	Found.	Calculated for $Zn_3P_2O_8.Zn(OH)_2$.
ZnO . . .	66·6 . . .	67·1
P_2O_5 . . .	29·2 . . .	29·2
H_2O . . .	3·8 . . .	3·7
	99·6	100·0
Sp. gr. . .	4·12 . . .	—

Tarbuttite is therefore a basic zinc phosphate with the formula

$$Zn_3P_2O_8.Zn(OH)_2 = Zn_2(OH)PO_4 = 4ZnO.P_2O_5.H_2O,$$

corresponding to, though not isomorphous with, the orthorhombic

adamite $Zn_3As_2O_8.Zn(OH)_2$. Although several zinc phosphates have been prepared artificially, no basic phosphate appears to have been hitherto described.

The water is lost only at a red-heat; there was no loss at 370° C. A second determination of the loss on ignition, made on another sample weighing 1·554 gram, also gave 3·8 per cent. Another analysis, made on slightly impure pseudomorphous tarbuttite, is given below (p. 29).

Pseudomorphous tarbuttite.

With the exception of hopeite and parahopeite, tarbuttite was one of the latest minerals to be formed at the locality, and it has clearly resulted by the action of phosphatic solutions on the earlier formed secondary minerals in the upper, ozidized zone of the deposit of ore. The larger crystals of tarbuttite with the associated crystals of pyromorphite (lead phosphate) must have been formed by the action of such solutions on the mixed zinc and lead ore, which consists of an intimate intermixture of hemimorphite and cerussite with interspersed limonite. The occurrence of vanadates (descloizite and vanadinite), also of a late date of formation, points to the presence of solutions containing vanadium.

Tarbuttite after calamine.—A form of tarbuttite which is particularly abundant consists of mamillated masses and concentric shells of finely crystalline material. These masses are covered on their free surfaces with small, bright crystals of tarbuttite, and on the fractures they show the sparkling, pearly cleavage characteristic of the mineral; the whole of the material consists, in fact, of an aggregate of crystals or crystalline grains, which measure about $\frac{1}{2}$ to 1 mm. across. This form of tarbuttite has resulted from the alteration of calamine ($ZnCO_3$). On two specimens some of the unaltered calamine still remained as compact, mamillated masses; and here it was clearly seen that the alteration to tarbuttite had proceeded along the concentric layers of the original mineral.

Between the concentric shells of tarbuttite there is often a free space, and both surfaces of the shells are encrusted with crystals. These shells of tarbuttite do not exceed a few millimetres in thickness, and the material of adjacent layers may differ slightly in colour; for instance, pale green in one layer and colourless or grey in the next, and often reddish on the top layer. Sometimes these thin, curved layers of tarbuttite are found quite separated from other layers. The fact that spaces are left between the shells indicates that some of the zinc must

have been removed in solution, for the molecular volumes of calamine ($113{\cdot}6 = 28{\cdot}4 \times 4$) and of tarbuttite (117·5) are practically identical.

On these specimens of tarbuttite pseudomorphous after calamine no other mineral but tarbuttite could, as a rule, be detected under the lens; but on some of them small crystals of parahopeite, calamine, &c., were found (see below). The following analysis was made on 0·984 gram of material from one of the mamillated specimens, which was at first believed to consist wholly of tarbuttite:—

ZnO	65·3
P_2O_5	30·2
H_2O	4·1
CuO	trace
	99·6
Sp. gr.	4·06

At 220° C. there was a loss in weight of 0·2 per cent. These values are near to the corresponding values for tarbuttite; but the slight excess of water and phosphoric acid, and the slight deficiency of zinc, as well as the slight loss of water at 220° C. and the low specific gravity, all point to the presence of a small proportion of parahopeite intermixed with the tarbuttite.

On one or two specimens of a similar character a few minute crystals of parahopeite were afterwards detected. These were found resting on the shells of tarbuttite, and they have, no doubt, resulted from the subsequent alteration of the tarbuttite.

On other specimens of rather a different character, but also probably pseudomorphous after calamine, the crystalline crusts showed minute crystals of hemimorphite and calamine side by side with crystals of tarbuttite. Fragments of the crust when examined chemically were found to contain zinc and water, with phosphoric, silicic, and carbonic acids. Even when examined under a high-power lens there was little or nothing to suggest but that the minute, water-clear crystals were all of the same kind. But on heating a fragment in a bulb-tube a difference in behaviour was at once apparent: spike-like crystals of calamine became bright yellow in colour and remained yellow after cooling; the tarbuttite was bright yellow when hot and white when cold; and the hemimorphite was faintly yellow when hot and white on cooling. The microscopical examination of fragments of the crystalline crust crushed in oil also confirmed these results: through the cleavage-flakes of tarbuttite was seen a negative biaxial interference-

figure at the edge of the field; the calamine cleavages gave a negative uniaxial figure, also at the edge of the field; and the cleavage laths of hemimorphite gave straight extinction and no optic figure, or when viewed through *b* (010) the obtuse negative bisectrix.

Some of these pseudomorphous specimens showed indications of many complex stages of alteration, and could not always be satisfactorily made out. On some of them the tarbuttite crystals themselves are white and opaque on their surfaces, due to the alteration of tarbuttite to perhaps parahopeite or hydrozincite.

Tarbuttite after descloizite.—On the pseudomorphs of tarbuttite after calamine, above described, there are no indications of any crystalline form of the original mineral; only the mamillated surfaces of the massive calamine are represented. Specimens of tarbuttite pseudomorphous after descloizite, on the other hand, clearly show the outlines of the original crystals of descloizite. These are lenticular or tabular in habit, exactly like the large crystals of unaltered descloizite found at the locality (fig. 7 *c*, p. 32). These pseudomorphous crystals are hollow, and they measure up to about a centimetre across; their surface is minutely crystalline, and they consist wholly of a granular aggregate of very small crystals of tarbuttite. The few specimens of this kind which I have seen are of a bright reddish colour; the tarbuttite crystals being tinged, on the surface of the pseudomorphs, with iron hydroxide.

Tarbuttite after hemimorphite (?).—On one specimen, granular aggregates of reddish tarbuttite have the form of flat prisms, about $\frac{1}{2}$ cm. in length, standing out from the surface of tarbuttite pseudomorphous after calamine. The appearance of these pseudomorphous crystals rather suggested that the original mineral might have been hemimorphite, but there was no means of proving this. On the surface of this specimen the granular tarbuttite is also aggregated in arborescent forms.

Tarbuttite from the Bone-cave.

The description of tarbuttite so far given is based solely on material from Kopje No. 2. The mineral, however, also occurs in association with hopeite, in the bone-cave in Kopje No. 1, but only as very minute (about $\frac{1}{10}$ mm. across) and obscure crystals. Indeed it would have been impossible to determine this material had not the characters of the mineral been previously made out on the larger crystals.

As mentioned on p. 5, tarbuttite forms a skin of minute crystals

on the thin crust of hemimorphite which coats the surface of the bone-breccia. The material is also mixed with calamine, and it was almost impossible to isolate the mineral free from impurity. The fragments collected sank in methylene iodide; and when heated in a bulb-tube they behaved like tarbuttite. Dissolved in a drop of hydrochloric acid on a microscope-slide, the solution gave with ammonia a white precipitate, which was soluble in excess, and from this, ammonium sulphide gave a white precipitate; the latter was dissolved in a drop of nitric acid and a yellow precipitate was produced with ammonium molybdate. Zinc and phosphoric acid are therefore present: in larger fragments, silicic and carbonic acids were also detected. Fragments when crushed in oil gave cleavage-flakes with an extinction angle of 34° and showed the characteristic interference-figure of tarbuttite.

In the same way, the minutely crystallized encrustation on one of the bones was identified as tarbuttite (p. 38).

Descloizite.

Descloizite occurs in large quantities, and I am informed that several tons of it were thrown away on the dumps. It forms more or less cavernous masses mixed with limonite. Usually it is associated with yellowish crystals of tarbuttite, or less frequently with crystals of pyromorphite or quartz; all these minerals being of later date than the descloizite. The material is crystallized, and on the free surfaces is developed as somewhat rough crystals. Some of the specimens consist wholly of an aggregate of descloizite crystals each measuring a centimetre across. On one specimen a few small crystals of descloizite are implanted on the mamillated surface of calamine.

The crystals are dark brown in colour and have a bright, sub-metallic lustre; sometimes the crystals are partly altered and are dull on the surface. On the fractured surfaces the colour is lighter and the lustre resinous in character. The streak is yellowish-brown or buff-coloured. The mineral is brittle, and there is no cleavage. Chemical tests showed the presence of vanadium, lead, zinc, and a little water and copper; and the absence of arsenic, phosphoric acid, and chlorine.

The crystals exhibit a sub-parallel grouping of individuals with frequent repetition and rounding of the faces. Only approximate goniometric measurements could therefore be obtained, but sufficiently close to identify the forms. Three habits of crystals may be distinguished:—

(i) Pyramidal (fig. 7 *a*), with the forms[1] *b* {010}, *s* {310}, *m* {110}, *l* {130}, *u* {011}, *v* {021}, *o* {111}, *ϵ* {211}.

(ii) Prismatic (fig. 7 *b*), with the same forms as in habit (i), and differing only from this in the greater width of faces in the zone [100].

(iii) Tabular or lenticular (fig. 7 *c*), with the forms *a* {100}, *s* {310}, *m* {110}, *u* {011}, *o* {111}. The large face *a* is often much rounded, giving rise to lenticular forms.

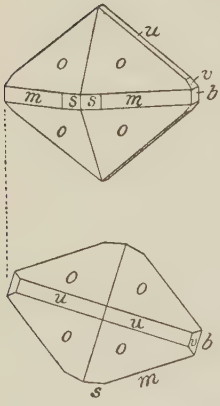

Fig. 7 *a*.

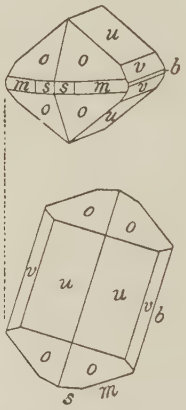

Fig. 7 *b*.

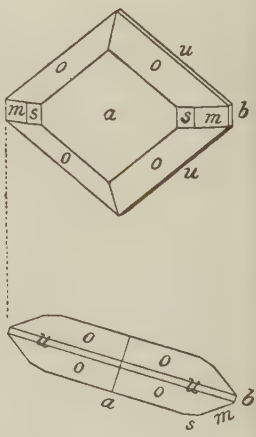

Fig. 7 *c*.

Crystals of descloizite from Broken Hill, North-Western Rhodesia.

The new form *s* {310} was present on five of the seven crystals which were measured; the angles are:—

	Calculated.	Measured.
$ss''' = (310) : (3\bar{1}0)$	24° 30′	22° – 24°
$sm = (310) : (110)$	20 14½	19 – 21

The distribution of the faces and the measurements accord with orthorhombic symmetry, as also do the optical characters, so far as these could be determined. Light is transmitted through the thinner crystals of tabular habit, and on the face *a* the direction of optical extinction bisects the angle between the edges of *o* {111}. No optical interference-figure was visible through *a* with a $\frac{1}{12}$-inch oil immersion. The dichroism on this face is distinct, being reddish-brown for vibrations

[1] Letters and indices as given in Dana's 'System of Mineralogy', 6th edit., 1892.

parallel to the *b*-axis and yellowish-brown for vibrations parallel to the *c*-axis. Small irregular fragments crushed in oil were seen to be even more strongly dichroic.

Vanadinite.

This is present on almost all the hopeite specimens in the form of botryoidal masses of a light-brown colour. The small globules often form branching aggregates somewhat resembling moss or broccoli. The surface is quite smooth without any indication of crystallization. The material is very brittle. When crushed under the microscope the globules show a radiated structure, and, being birefringent, they give a black cross parallel to the vibration-directions of the crossed nicols. Chemical tests showed the presence of vanadium, lead, and chlorine; and the absence of phosphoric acid.

The mineral is of quite recent formation. It is anterior to the hopeite crystals, but posterior to the thin crust of hemimorphite and tarbuttite which coats the bone-breccia; and it is often seen encrusting small bones which project from the surface.

In appearance the mineral is very like some of the vanadinite from Wanlockhead in Scotland: but its occurrence as a mineral of recent formation on bone-breccia seems to be unique.

Pyromorphite.

Small crystals of pyromorphite occur in association with tarbuttite, descloizite, and limonite in Kopje No. 2. Nearly all the specimens with the larger tarbuttite crystals show crystals of pyromorphite resting on the cellular limonite; the tarbuttite crystals rest on the pyromorphite when they are not in contact with the limonite. The association of pyromorphite with descloizite is less frequent. Some specimens consist wholly of a loose aggregate of small yellowish crystals of pyromorphite.

The crystals vary from a fraction of a millimetre up to about a centimetre in length. The smaller crystals are almost, or sometimes quite colourless and transparent, while the large ones are usually pale green and nearly opaque. The long-prismatic habit of the crystals is without variation; and the only forms present are the hexagonal prism $m\ \{10\bar{1}0\}$ terminated, often at both ends, by the low hexagonal pyramid $x\ \{10\bar{1}1\}$. The angle mx was measured as 49° 29′–49° 40′, and the angle xx in the same zone over the apex of the crystal as 80° 10′–80° 48′. The faces though bright are slightly hummocky.

Two, but only two, instances were found in which two crystals were grown together nearly at right angles and with one pair of prism-faces coincident. Twinned on {33$\bar{6}$4} the angle between the principal axes would be 95° 40′. The angle, as measured under the microscope, between the prism-edges of one crystal and those of the other was 97° in one instance and 90° in the other. These, therefore, are probably only accidental attachments of crystals and not regular twin intergrowths.

Chemical tests of the pyromorphite crystals showed the presence of lead, phosphoric acid, and chlorine. Three crystals were separately tested for arsenic, but this was not detected.

Hemimorphite.

Zinc silicate is one of the most abundant of the minerals at this locality, but only rarely is it distinctly crystallized, and finely crystallized specimens were not seen. The bulk of the oxidized ore consists of an intimate mixture of hemimorphite and cerussite with variable amounts of interspersed limonite. Thin sections of this ore show, under the microscope, radiating groups of hemimorphite needles with grains and indistinctly bounded crystals of cerussite. On the walls of cavities are small radiating tufts of indistinct crystals. Even on larger specimens of this character the crystals are much intergrown and very indistinct. Small tufts of more freely developed crystals of hemimorphite, about $\frac{1}{2}$ to 1 mm. in length, are thickly clustered on almost all the crystals of cerussite on those specimens in which the latter is distinctly crystallized. On one specimen, with crystals of cerussite, a loose, confused (not radiating) aggregate of minute crystals of hemimorphite had quite the appearance of drifted snow.

The crystals of hemimorphite are tabular in habit parallel to the brachypinacoid, and show the forms $b\{010\}$, $m\{110\}$, $s\{101\}$, and sometimes $c\{001\}$. In all cases the crystals are colourless and transparent.

Mamillated crusts of hemimorphite with a pale bluish tint also occur, but appear to be rare. Compact, dark-brown material mixed with much limonite, and sometimes containing a little phosphoric acid (probably as tarbuttite), was also represented in the various collections.

Crystals of hemimorphite belonging to a later period of growth also occur. For instance, minute rosettes of colourless or reddish hemimorphite crystals are sometimes to be seen on the larger crystals of tarbuttite; and a similar group was noted on a crystal of quartz. As mentioned above (p. 29), minutely crystallized hemimorphite occurs in the pseudomorphous crusts of tarbuttite after calamine.

Hemimorphite is also present in the crystallized crusts on the bones and on the bone-breccia in the cave in Kopje No. 1 (pp. 5, 38). On the bone-breccia, the lower part of the crust usually consists of finely fibrous hemimorphite, and amongst the minute ($\frac{1}{10}$ to $\frac{1}{4}$ mm.) crystals on the surface, pale yellowish crystals of hemimorphite were detected, together with crystals of tarbuttite and calamine (p. 30). Similar pale yellowish crystals were present in abundance on two of the bones examined: these crystals have not at all the appearance of hemimorphite, being quite short and of a thick-tabular, rhombic habit; further, they show no radial grouping, but are confusedly aggregated. On one of the larger of them, measuring about $\frac{1}{2}$ mm. across, the forms, as determined on the goniometer, are b {010}, m {110}, t {301}, h {021}.

Calamine.

Zinc carbonate appears to occur quite apart from the ordinary type of ore, no trace of it being detected in the mixture of hemimorphite and cerussite. It forms mamillated masses with a concentric structure and a smooth or indistinctly crystallized surface; the colour is white, pale yellowish, or brown. A mass weighing several hundredweights is exhibited in the Rhodesia Museum at the London offices of the British South Africa Company. Dark brown or dark grey, friable to compact masses, mixed with much limonite, also occur; and in one instance a light-grey marly material proved, on examination, to be calamine.

The mamillated calamine has been in many cases partially or completed altered to tarbuttite; and on the surface of this pseudomorphous material, either mixed with the tarbuttite crystals or resting on them, there is sometimes a later growth of a few small ($\frac{1}{2}$–1 mm.) crystals of calamine. These crystals are transparent with a pale yellowish colour; they are of an acute, spike-like habit, and their faces are rough and drusy. Goniometric measurement of one crystal proved the forms to be the scalenohedron v $\{20\bar{1}\} = \{21\bar{3}1\}$ and the acute rhombohedron s $\{223\} = \{05\bar{5}1\}$; while on another measured crystal only s was developed.

Hydrozincite (?).

On the surface of those crusts of tarbuttite pseudomorphous after calamine which are intermixed with hemimorphite and calamine (p. 29) there are a few minute hemispherical masses which are white and earthy and quite soft. This material was found to contain zinc, carbonic acid, and water, and is therefore probably hydrozincite. It was the last

mineral to be formed. On the same specimen there is, however, an opaque, white crust, beneath the surface crystallized layer, which also contained zinc, carbonic acid, and water, together with some phosphoric acid; this is also possibly hydrozincite, but may be earthy calamine, mixed with tarbuttite or parahopeite.

Cerussite.

Cerussite not only forms a large part of the massive ore (p. 34) but is also of common occurrence in cavities of the ore as fine groups of magnificent crystals. Perfectly colourless and transparent crystals bounded by a profusion of brilliant faces reach a size of $1\frac{1}{2}$ cm.; while still larger crystals with a slightly yellowish tinge and drusy surfaces measure up to 7 cm. in length. These cerussite crystals are almost invariably encrusted with tufts of minute crystals of hemimorphite.

The crystals are elongated in the direction of brachyaxis a [100], and are either prismatic in habit, or are tabular parallel to the brachypinacoid b {010} or to the basal pinacoid c {001}. Twinning on m (110) is frequent, giving rise to the six-rayed groups of crystals so characteristic of cerussite. On one twinned crystal, consisting of two individuals, the following forms[1] were determined:—

$a\{100\}$, $b\{010\}$, $c\{001\}$; $m\{110\}$, $r\{130\}$; $y\{102\}$; $x\{012\}$, $q\{023\}$, $k\{011\}$, $i\{021\}$, $t\{061\}$; $p\{111\}$, $o\{112\}$; $s\{121\}$.

On another measured crystal the forms were $a\,b\,c\,m\,r\,y\,k\,i\,p$ and $z\{041\}$; and on a third $b\,c\,m\,y\,x\,i\,p\,o$.

A very curious and remarkable form of cerussite is represented by some short stalactitic growths, which, I am told, are being formed at the present day on the walls of the bone-cavern. One of these stalactites, which I examined, has a length of $2\frac{1}{2}$ inches and a diameter of $1\frac{1}{2}$ inch; and shows transverse corrugations or flutings on the surface. On the upper surface of these flutings there is a slight yellow stain of iron hydroxide, but the remainder of the stalactite is pure white, with somewhat the texture of snow. The material is loose and friable, and consists of an aggregation of minute crystals without any definitely orientated directions. When a fragment of the stalactite is crushed in oil and examined under the microscope, vast numbers of isolated crystals are seen. These have the form of short needles or rods, measuring about $\frac{1}{5}$ mm. in length and $\frac{1}{30}$ mm. in thickness, and extinguishing between crossed nicols parallel to their length. Sometimes, though rarely, the

[1] Letters and indices as in Dana's 'System of Mineralogy', 6th edit., 1892.

rods are arranged in stellate groups and show other indications of twinning. A chemical examination of the material proved it to be lead carbonate.

Limonite.

Limonite is of common occurrence with all the secondary minerals in Kopje No. 2. It forms cellular or stalactitic masses; it may be hard and dark brown in colour, or soft and ochreous. A bright yellow, ochreous deposit on the surface of some crystals of hemimorphite at first suggested cadmium-ochre (greenockite), but on examination it proved to be only limonite.

Wad.

A soft, powdery form of manganese oxide sometimes occurs as a thin coating on the mamillated surfaces of tarbuttite pseudomorphous after calamine; so that the specimen as a whole rather resembles psilomelane. Very small nodular masses with a concentric shelly structure, and consisting of soft, black wad, occur in the limonite of one or two of the tarbuttite specimens.

Quartz.

The common mineral quartz is conspicuous by its rarity at this locality: only on three specimens was it detected. Silicate of zinc (hemimorphite) is, however, of abundant occurrence.

Small, rounded grains of yellowish quartz were found in a clayey matrix on one of the hopeite specimens. A crust of small quartz crystals (*m r z*), of a pale yellowish colour and transparent, is present on one of the descloizite specimens; at first sight this looked very like the crust of yellowish tarbuttite which is usually associated with descloizite. Small crystals of quartz were also found on the surface of a specimen of compact ferruginous hemimorphite; on the surface of one of the quartz crystals a small tuft of colourless crystals of a later growth of hemimorphite was noticed.

Flakes of opaque, white quartz, which have been worked by the hand of man, are found embedded in the bone-breccia of the cave.

Galena.

A few specimens of galena in ordinary cleavage masses were seen. On one of them, small crystals of cerussite are attached. Mr. Franklin White mentions the occurrence of small nodules of galena embedded in the clay of the bone-cavern, and he expresses the opinion that they have been formed in situ (possibly by the reducing action of animal matter).

Blende.

Massive zinc-blende with yellow cleavage surfaces was seen embedded in pieces of a very fine-grained, crystalline limestone of a bluish-grey colour.

All the secondary zinc and lead minerals described above have without doubt resulted from the alteration of blende and galena, which as yet have been met with in only small quantities.

APPENDIX.

Replacement of the Bones by Zinc and Lead Minerals.

A few of the bones from the hopeite cave were examined to ascertain how far their material had been replaced by zinc phosphates. One bone, which showed no crystalline structure, was found to consist mainly of calcium phosphate and carbonate, with a little zinc and lead, and practically no organic matter: the specific gravity was about 2·85. Another bone, which had evidently been more altered and was thickly encrusted with minute crystals, both on the exterior and in interior cavities, was found to consist, in the compact portions, of calcium phosphate and carbonate with considerable amounts of zinc and lead: the specific gravity of the compact portion was in this case 3·25.

The crystallized crusts on and in the bones consist of very minute (about $\frac{1}{10}$ mm. across) crystals closely and confusedly aggregated; and it was not always possible to determine the mineral-species to which they belong. In similar crusts on the surface of the bone-breccia, hemimorphite, tarbuttite, hopeite, calamine, and vanadinite were determined. On one or two specimens, minute tufts of colourless, acicular crystals of hopeite were present in the cavities of bones and teeth. The larger and more distinctly developed crystals of hopeite are never in contact with the bones, but always separated from them by the crusts of hemimorphite, vanadinite, &c. In the crystallized crust on one bone minute yellowish crystals of tarbuttite (p. 31) were detected; and on two others yellowish crystals of hemimorphite (p. 35). Hemimorphite appears to be the most frequent of the crystallized minerals replacing the bones. Small bones projecting from the surface of the bone-breccia are sometimes completely enveloped by vanadinite (p. 33). This was the only lead mineral found in association with the bones, but it is probable that most of the lead which they contain is present as carbonate, though crystals of cerussite could not be detected.

Communications from the Oxford Mineralogical Laboratory. No. X.

Note on the crystallization of potassium bichromate.

(*With Plate I.*)

By Professor H. A. Miers, D.Sc., F.R.S.

[Read November 12, 1907.]

IF a drop of strong solution of potassium bichromate, placed upon a microscope-slide, be observed under the microscope as it crystallizes, and if the drop be sufficiently thin, it will generally be found that the following events take place: The first crystals make their appearance at the edges of the drop and after growing rapidly for a short period as branching fibres, they begin to grow quietly in the form of plates or flattened rods presenting the characteristic form of the crystals of this substance. These crystals continue to grow uniformly, but after a short period, at a distance from the growing crystals, and at some spot where the drop is thin, a fresh crystalline growth starts suddenly from a point, and extends with great rapidity in all directions in the form again of branching needles and fibres. After a short period this rapid growth ceases and each of the fibres swells out at the end into a well-defined crystal and continues to grow slowly and uniformly as a single, regular plate. The process may be repeated by the sudden development of a new spontaneous growth in another portion of the drop, and the same succession of events may be repeated again and again. Sometimes these successive growths constitute a series of rings approximately parallel to the edges of the drop which follow one another till the centre of the drop is reached.

The figures on plate I are photographic reproductions of such drops taken during the act of crystallization, and they show very clearly the manner in which spontaneous crystallization, starting from a point not far from the centre of fig. 1, has spread in all directions as a rapid, fibrous growth, succeeded by the development of elongated plates. Fig. 2 shows the same thing near the edge of the drop. It will be noticed also that the rapid, fibrous growth has been suddenly checked

where it has approached the large crystals growing in another portion of the drop.

It has been shown by the author and Miss F. Isaac[1] that many aqueous solutions as they cool pass into a 'metastable' condition in which crystallization can only be started by the introduction of a crystal, which proceeds to grow slowly, and then into a 'labile' condition in which spontaneous crystallization takes place, and in which, owing to the increased supersaturation, the crystalline growth is rapid. The passage from one state to the other is indicated both by a sudden change in the refractive index, and also by the shower of crystals produced if the liquid be agitated. It has been shown by Mr. J. Chevalier,[2] working in my laboratory, that with a solution of potash-alum, octahedral crystals grow in the metastable solution, but that the alum crystallizes in fine fibres when the solution is in the labile condition.

Bearing these facts in mind, a simple explanation suggests itself for the remarkable periodic crystallization exhibited by potassium bichromate. Crystals appear at the edge of the drop where, owing to evaporation or cooling, the solution is sufficiently strong to be in the labile condition, and proceed as rapidly growing fibres; but so soon as these have by their growth reduced the strength of the solution in their neighbourhood to the metastable state they continue to grow quietly and uniformly; presently, however, at some point sufficiently distant from the growing crystals to be also in the labile state, crystallization starts afresh, either spontaneously or perhaps through inoculation by a crystalline speck falling into the drop from the air. This again proceeds as the rapid, fibrous growth, characteristic of the labile condition, until again the liquid passes into the metastable state and the growth is slow. Miss Isaac has kindly made some experiments by the method of refractive indices and the appearance of showers in the stirred solution, and has determined the following as the temperatures at which solutions of potassium bichromate of certain strengths became saturated and labile respectively.

Weight of salt in 100 parts of water.	Saturated at	Labile at
17·266	28·5° C.	18·5° C.
20·00	32·2°	22°
29·09	43·5°	34°

[1] Journ. Chem. Soc., 1906, vol. lxxxix, pp. 413–454.

[2] Min. Mag., 1906, vol. xiv, pp. 134–142.

Sometimes a growing crystal suddenly enters a portion of the drop where the solution is labile, and becomes a centre of crystalline growth, so that from its point a number of the fibrous needles start out in all directions.

The passage from the one condition to the other is quite sharp and sudden, and the different parts of the drop may be distinguished; where the solution is labile, the introduction of a crystal produces the rapid, fibrous growth; where it is metastable, the growth is regular and slow. This is the reason why the rapid growth ceases as soon as the fibres enter the zone of metastable solution surrounding the plates.

I have suggested elsewhere[1] that needle-shaped crystals are characteristic of growth in a labile solution, because the growing crystal is surrounded by a protecting sheath of metastable liquid, except at one point where it is in contact with the labile solution.

A few examples of periodic crystallization have been previously recorded by other observers, although different explanations have been offered of this curious phenomenon. For example, Alexéeff[2] states that molten ethyl ethanetetracarboxylate, when crystallizing in thin layers, solidifies in concentric zones surrounding the centre where crystallization first began, and if the supercooled ester be inoculated, crystallization after proceeding for a certain time in all directions is suddenly checked and is then renewed. He records similar effects with supercooled benzophenone and coumarin. He attributes this behaviour to changes in the surface tension due to heating by crystallization. It appears to me much more likely that it is an example of the same process which takes place with potassium bichromate.

[1] Science Progress, 1907, vol. ii, p. 128.

[2] Journ. of the Russian Physico-Chemical Society, 1906, vol. xxxviii, p. 1120.

Communications from the Oxford Mineralogical Laboratory. No. XI.

The question of a relation between the Parallel Growths of Crystals and Isomorphous Miscibility, and the bearing of Parallel Growths on questions of Isomorphism.

(*With Plate II.*)

By Thomas Vipond Barker, B.A., B.Sc. (Oxon.)
Senior Demy of Magdalen College, Oxford.

[Read November 12, 1907.]

I. The question of a relation between the Parallel Growths of Crystals and Isomorphous Miscibility.

ONE of the most important and striking properties of isomorphous substances is their capacity for forming microscopically homogeneous mixed crystals, the physical properties of which are, as Retgers has especially shown, intermediate between the properties of the constituents. With the great majority of isomorphous substances the mixed crystals can be obtained in all proportions, but with others the miscibility is limited.

The first case of restricted miscibility was discovered by Retgers[1] in potassium phosphate (mol. vol.=58·25) and ammonium phosphate (64·17) crystallizing in the tetragonal system; he did not determine the exact proportions which each salt can take up of the other, but estimated them to be about 20 per cent. each way. Krickmeyer[2] found later that the miscibility is much more restricted, for the ammonium salt will only take up as much as 5·5 per cent. of the potassium salt. The two salts are in all other respects similar to each other, on which account they were still regarded by Retgers as isomorphous. Potassium phosphate and arsenate (62·82) form mixed crystals in all proportions, as was proved

[1] Zeits. physik. Chem., 1889, vol. iii, p. 547.
[2] Zeits. physik. Chem., 1896, vol. xxi, p. 71.

by Muthmann and Kuntze.[1] The latter investigators also found that potassium permanganate (58·53) and rubidium permanganate (63·23) only mix in very restricted proportions, the miscibility scheme being: 1 per cent. $RbMnO_4$ . . . 8 per cent. $KMnO_4$; while the permanganate and perchlorate (54·91) of potassium are perfectly miscible. Again, although ammonium iodide (58·14) and potassium iodide (53·06) are miscible in all proportions,[2] and potassium chloride (37·49) and bromide (43·30) are nearly perfectly miscible,[3] sodium chloride (26·92) and potassium chloride on the other hand do not mix at all (Krickmeyer). Finally, potash alum (546·9) and thallium alum (566·6) are perfectly miscible, whereas sodium alum (549·9) and potash alum are quite immiscible (Krickmeyer).

Although in all the above cases, with the exception of sodium and potash alum, miscibility does seem to go hand in hand with closeness of molecular volume, the evidence would have remained very weak on account of the too small numerical differences, were it not for the more convincing work of Gossner and Wulff.

Gossner[4] observed that the isomorphous hexagonal salts $ZnSiF_6.6aq.$ (145·6) and $NiSiF_6.6aq.$ (144·6) mix in all proportions, while the former is quite immiscible with the isomorphous salt $ZnSnF_6.6aq.$ (166·0). The immiscibility is attributed by Gossner to the considerable difference of molecular volume. The justness of this view is greatly strengthened by the discovery of G. Wulff[5] that ammonium sulphate (74·63, Tutton) mixes completely to give perfect mixed crystals with rubidium sulphate (73·77) and also completely, though yielding somewhat less perfect crystals, with either potassium sulphate (65·33) or caesium sulphate (85·17); potassium and caesium sulphates, however, are totally immiscible, and Wulff points out that the inability to fit together so as to form mixed crystals must be due to the great difference of molecular volume.

Since miscibility and the formation of parallel growths are favoured by the same factor—closeness of molecular volume—it becomes of some importance to discover whether the two properties go absolutely hand in hand, and it was with a view to obtaining fresh evidence on this point that the following investigation was taken up.

[1] Zeits. Kryst. Min., 1894, vol. xxiii, p. 368.
[2] Gossner, Zeits. Kryst. Min., 1905, vol. xl, p. 69.
[3] Fock, Zeits. Kryst. Min., 1897, vol. xxviii, p. 351.
[4] Zeits. Kryst. Min., 1906, vol. xlii, p. 475.
[5] Zeits. Kryst. Min., 1906, vol. xlii, p. 558.

The Sulphate-chromate Group.

Although the miscibilities of the orthorhombic chromates of the alkali metals have not yet been determined, it seemed desirable to bring them into the scope of the experiments, so as to make the group serve not only to test the question concerning the connexion between miscibility and formation of parallel growths, but also to confirm, if possible, the author's previous results on parallel growths in general. The selenates could not be used on account of their high deliquescence. Good crystals of potassium, ammonium, and thallium sulphates are most difficult to obtain, but Dr. Tutton very courteously placed at the author's disposal excellent crystals of these salts, together with some pure caesium sulphate. The rubidium sulphate employed was purchased from Merck, and was part of the original stock used in the preparation of rubidium perchlorate and permanganate.

The chromates have not been so thoroughly investigated as the sulphates; the rubidium salt was measured by Piccard[1] and its optical properties and cleavage determined by Wyrouboff;[2] the specific gravity has not been previously determined. The caesium salt was measured by Fraprie,[3] who found it dimorphous, one of the forms being orthorhombic and isomorphous with the sulphate; the optical properties and the specific gravity were, however, not determined.

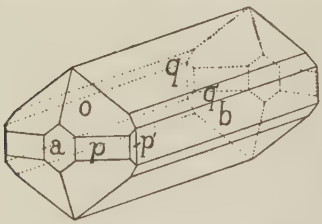

Fig. 1.—Rubidium chromate.

The rubidium and caesium chromates used in the present investigation were prepared by neutralizing rubidium hydroxide (Merck) and caesium carbonate (Merck) respectively with pure chromic acid. The salts were recrystallized.

Rubidium chromate.

System: Orthorhombic.

Ratios of the axes: $a : b : c = 0{\cdot}5666 : 1 : 0{\cdot}7490$ (Piccard).

Forms: $q = \{011\}$, $q' = \{021\}$, $b = \{010\}$, $o = \{111\}$, $a = \{100\}$, $p = \{110\}$, $p' = \{130\}$, and $o' = \{112\}$.

[1] Jahrb. prakt. Chem., 1862, vol. lxxxvi, p. 455.
[2] Bull. Soc. Min. France, 1881, vol. iv, p. 129.
[3] Zeits. Kryst. Min., 1906, vol. xlii, p. 113.

The forms a and p' are new, whilst o' was not observed by the author; the habit of the crystals is shown in fig. 1.

Fundamental angles: (Piccard) $q' : q' = 021 : 0\bar{2}1 = 112° 33'$.
$o : o = 111 : 1\bar{1}\bar{1} = 86\ 43$.

Angles of new forms:

	Observed.	Calculated.
$p : p' = 110 : 130$ ...	29° 58′ ...	30° 0′
$a : o = 100 : 111$ ...	43 26½ ...	43 21½
$a : p = 100 : 110$ ...	29 32 ...	29 32

Cleavage: basal (Wyrouboff).

Specific gravity (16°/4° C.) = 3·518. Mol. vol. = 81·61.

Solubility: 100 parts of water dissolve 73·24 parts at 17·6° C. and the specific gravity of the solution, at 17·6°/4° C. = 1·4897.

Caesium chromate.

System: Orthorhombic.

Ratios of the axes: $a : b : c = 0·5640 : 1 : 0·7577$ (Fraprie).

Forms: a, b, c, o, p, q, and q'. The habit is very similar to that of the rubidium salt.

Fundamental angles: (Fraprie) $b : p = 010 : 110 = 60° 35'$.
$b : q = 010 : 011 = 52\ 51$.

Cleavage: perfect parallel to b {010}, imperfect parallel to c {001}.

Optics: axial plane parallel to b {010}; first positive mean line normal to a {100}; birefringence, fairly strong; axial angle narrow, $\rho > v$.

Specific gravity (16°/4° C.) = 4·237. Mol. vol. = 90·14.

Solubility: 100 parts of water dissolve 71·35 parts at 13° C., and the specific gravity of the saturated solution, at 13°/4° C. = 1·5027.

Ammonium chromate crystallizes in the monoclinic system, and is isomorphous with the selenate, not with the sulphate.

The following are the molecular volumes of the salts used: the values for the sulphates are due to Tutton, and for the chromate of potassium to Gossner.[1]

	Sulphate.	Chromate.
Potassium ...	65·33 ...	70·39
Rubidium ...	73·77 ...	81·61
Thallium ...	73·98 ...	?
Ammonium ...	74·63 ...	(81·1)
Caesium ...	85·17 ...	90·14.

[1] Groth's 'Einleitung in die chem. Krystallographie', p. 46.

The author's usual method of observation was employed; fresh cleavages or sometimes crystals fresh from their solutions were taken, and on them were placed drops of the solutions of the other salts, the whole being observed under the microscope. To give the details of each experiment would be superfluous; the results are incorporated in the following diagram, which is constructed in exactly the same way as the one given in a former memoir [1] on the halogen salts of the alkalis. No decisive result could be obtained with the pairs denoted by a note of interrogation, owing either to the too rapid deposition of the solute or dissolution of the crystal. (See plate II, and explanation on p. 53.)

Results of Experiments on Parallel Growth.

Solutions.

Crystals.

Mol. Vol.	65·33	70·39	73·77	73·98	74·63	81·61	85·17	90·14
	$_2SO_4$	K_2CrO_4	Rb_2SO_4	Tl_2SO_4	Am_2SO_4	Rb_2CrO_4	Cs_2SO_4	Cs_2CrO_4
K_2SO_4		P	P	P	P	P	Ir	Ir
K_2CrO_4	P		P	?	P	P	P	Ir
Rb_2SO_4	?	P		?	Z	P	P	P
Tl_2SO_4	P	P	P		P	?	P	?
Am_2SO_4	P	P	?	P		?	P	Ir
Rb_2CrO_4	?	P	P	?	P			P
Cs_2SO_4	?	P	P	?	P	P		P (Z)
Cs_2CrO_4	?	Ir	P	?	Ir	P	P	

[1] T. V. Barker, Min. Mag., 1907, vol. xiv, p. 235.

A glance at the table shows that the irregular growths occur in the squares at the top right-hand and the bottom left-hand parts of the diagram: that is, in positions expressing greatest differences of molecular volume. The general results are, then, in accordance with the previous observations on parallel growths.

With respect to the connexion between miscibility and the formation of parallel growths, it is seen that among the sulphates the only case of irregular growth is with potassium and caesium sulphates (plate II, fig. 6), which are precisely the only pair (as yet investigated) which do not yield mixed crystals. In this group the limiting difference of molecular volume for parallel growths does happen to fall with that for miscibility, but this is probably only a coincidence, as will be seen from the results obtained with other non- or partially-miscible pairs of isomorphous substances.

Caesium chromate forms irregular growths on both potassium sulphate and chromate: this is in accordance with expectations. Whether caesium and potassium chromates are miscible or no, is a question the author hopes to examine experimentally.

Other immiscible Pairs of Substances.

Potassium and ammonium phosphates readily give beautiful parallel growths; and, since the solubilities are sensibly equal, the growths may be obtained in either direction—using either substance as crystal or as solute. The growths are so perfect as to be almost of a zonal character, and are formed equally readily on natural faces of the prism or pyramid forms.

Whether rubidium and potassium permanganates form parallel growths on each other has not been decided, owing to the opacity of the crystals; numerous attempts were made to illuminate the slide from above but without success. Potassium perchlorate and caesium permanganate, however, do form parallel growths, and, as the difference of molecular volume is here much greater than with the former pair, it may be safely assumed that the growths are in reality parallel.

Of the remaining pairs mentioned, sodium and potassium chlorides, potassium chloride and bromide have been previously proved to form parallel growths[1]; sodium and potassium alum probably form zoned crystals. The growths of zinc silico- and stanno-fluorides have not been investigated for want of material.

[1] Min. Mag., 1907, vol. xiv, p. 235.

The present experiments prove that there is no direct connexion between formation of parallel growths and of mixed crystals, although these two properties are favoured by the same factor—similarity of molecular volume; for the necessary closeness of the molecular volume, or of the topic axes, is much greater for miscibility than for parallel growth. The experiments therefore shed some light on the much debated question of the constitution of a mixed crystal. The two views held are: (1) a mixed crystal is a parallel growth of layers (or an intercalation of crystalline pieces) of the two constituents, the fragments coming together without any complete continuity of the same space-lattice mesh across the boundaries between the different constituents; (2) the mixing is of a more intimate nature, one or more atoms of one constituent being replaced, here and there, at some of the nodes of the same space-lattice by a corresponding atom or atoms of the other; so that atoms or radicals common to the constituents are continuously disposed, to form a single set of congruent space-lattices extending throughout the single mixed crystal. Although the optical properties of mixed crystals were formerly expected to throw some light on the subject, yet Pockels [1] finds the present optical data to be insufficient to discriminate between the alternative views, i.e. whether one atom replaces another, or whether crystalline pieces are grown together in parallel position.

The evidence afforded by the present experiments is decidedly against the validity of regarding mixed crystals as parallel growths in the ordinary sense, for if they were, substances which do not mix at all or only partially should not be capable of giving parallel growths, whereas in reality they are.

Another essential difference between mixed crystals and parallel growths is found in the gradual change in the values of the angles of mixed crystals with the composition. When one substance grows in parallel position on another, the values of the angles of the crystals deposited do not tend to approximate to those of the mother-crystal: this was conclusively proved during the investigation of the growths of crystals of potassium perchlorate on barytes.[2] But when mixed crystals are formed the structures accommodate themselves to each other, the result being a structure with intermediate angles. This give and take must be greatly facilitated by the circumstance that the substances come together in the liquid condition, and the accommo-

[1] Neues Jahrb. Min., 1893, Beilage-Band viii, p. 117.

[2] T. V. Barker, Journ. Chem. Soc., 1906, vol. lxxxix, p. 1143.

dation takes place before, or at least during, solidification; but in the formation of a parallel growth, one of the surfaces is already in the solid condition and cannot therefore alter its dimensions to become absolutely congruent with the liquid substance, nor is it found to induce congruence in the latter. In spite of this, since the structures are similar and nearly congruent, the crystal has sufficient influence on the liquid substance to bring at least one line of particles of very small extent into congruence with a similar line in itself, and, when once this has been effected, the tiny crystals proceed to grow on their own account, just as they would on an amorphous surface, and therefore with the preservation of their own particular angles.

II. The bearing of Parallel Growths on questions of Isomorphism.

The later definition of isomorphism by Mitscherlich was: 'Substances possessing an analogous composition, which crystallize in the same form (or in similar forms), and which are capable of mixing in all proportions, are isomorphous.' This definition, though very useful at the time it was enunciated, is now arbitrary and unsatisfactory for the following reasons:—

(1) The term 'analogous' must not be interpreted too closely, for many compounds are universally admitted to be isomorphous, although the replacing elements or groups are dissimilar. Thus, the ammonium salts are held to be strictly isomorphous with the alkali salts; the cyanides with the haloids; the groups NaSi and CaAl replace each other isomorphously in the felspars; CaSi and 2Al in the pyroxenes; and TiF_2, NbOF, and WO_2 in the compounds described by Marignac.

(2) Similarity of form and angle are found with substances which probably differ in symmetry, e.g., $KLiSO_4$ and $NaLiSO_4$, and it is very difficult to decide whether such compounds ought to be regarded as isomorphous. Again, all cubic substances necessarily possess the same angles.

(3) The researches of Retgers, Krickmeyer, Fock, Gossner, Wulff, and others have shown that many substances, which in all other respects exhibit the properties characteristic of isomorphous substances, do not form mixed crystals in all proportions.

Two other properties have been long advanced as characteristic of isomorphous substances:—(1) the formation of parallel growths; (2) the

relief of supersaturation of a solution by inoculation with a substance isomorphous with the solute.

It would be very difficult to offer a definition free from objection. The cause of this is to be found in the fact that the degree of similarity between pairs of isomorphous substances is by no means always the same: nor could this be expected; for, to take an example, even if, as in the cubic system, the angles remain constant, yet each compound has its own molecular volume, which is quite different from those of the isomorphous compounds, and it has been recently proved that those very properties which are used as tests for isomorphism, depend greatly on the value of the molecular volumes. Again, if the miscibility be considered, it will be found that some substances mix in all proportions, whilst other compounds do not, although in all other respects they may be just as similar to each other as the former.

Although isomorphism is difficult to define, there is no doubt that its cause is to be sought in a similarity of structure, by which one means that the points at which the chemical atoms or molecules are situated, are distributed in space in a similar manner. Since any particular form of assemblage must be an equilibrium arrangement due solely to the interaction of forces between the constituent atoms or molecules, it follows that the forces obtaining in compounds built up on the same chemical type will favour similar structures. Compounds of the same type are generally obtained by replacement of elements by others belonging to the same group of the periodic system, whereby the chemical structure (distribution of valencies) remains the same, and of late years Mitscherlich's term 'analogous chemical composition' has been narrowed down to connote this type of replacement alone. This limitation is quite arbitrary: the types of the compounds $NaNO_3$ and $CaCO_3$, $KClO_4$ and $BaSO_4$ are just as analogous as those of the compounds K_2SO_4 and Rb_2SO_4, and much more so than those of the compounds $(NH_4)_2SO_4$ and K_2SO_4.

Similarity of structure gives rise to similarity of physical properties, and it is by means of the latter that the former can be detected. The three chief properties used in the determination of crystal structure are: (1) cohesion (cleavage and elasticity relationships), (2) formation of parallel growths, and (3) the formation of mixed crystals.

(1) The cleavage-directions are of great value in the determination of crystal structure; all the members of a well-defined isostructural group exhibit the same cleavage-directions, although the degree of perfection is, of course, not always the same.

(2) When a regular growth of any kind takes place there is undeniable evidence of some similarity of structure, for the only conceivable cause is a fitting together of two similar structures. The fitting may be possible only along a particular line or plane, as in most of the regular growths met with in the mineral kingdom, e.g., rutile on haematite, or as in some artificially obtained regular growths, e.g., potassium iodide on mica. In other cases, however, the fitting can take place along any line or plane, which proves that to each and every line or plane in one structure, there is a similar line or plane in the other: in other words the whole structures are similar and the two substances are isostructural. When parallel growths of this nature can be obtained, there is overwhelming evidence for regarding the substances in question as possessing absolutely similar structures.

The usefulness of parallel growths in determining whether two substances are isostructural or not, is somewhat weakened by the fact that to obtain them it is not only necessary to have similar structures, i.e., structures possessing the same point-systems, but the distances between the points (topic-axes) must be sensibly equal. This drawback disappears when we are dealing with large groups of substances, for the differences between the topic-axes of consecutive members is generally small. Thus the fact that rubidium sulphate forms parallel growths on either potassium or caesium sulphate, no matter which crystalline form be used, proves that it is isostructural with both, and, hence, that the latter are themselves isostructural.

(3) The formation of mixed crystals was considered by Retgers to be the most important property of isostructural substances. But, just as with parallel growths, the absence of formation of mixed crystals cannot be taken as decisive evidence against the presence of similarity of structure. An additional drawback is also found in the formation of mixed crystals by substances which are certainly not isostructural.

Besides the above three principal methods of exploring crystal structure, a general comparison of the physical properties may be of use, but this method must be used with some caution, for although isostructural substances will necessarily possess similar angles, forms, optical properties, &c., some of these may nevertheless be exhibited by quite dissimilar substances; thus, all cubic substances must exhibit much the same forms, and the angles between them are, of necessity, constant. It is in such cases as these that a study of parallel growths is especially useful.

The ready formation of parallel growths has led some investigators, and notably Tschermak, to the conviction that sodium nitrate and calcite are to be regarded as isomorphous, but little significance has been attributed to this wonderful property by others, partly no doubt because the case was unique. Retgers asserted that parallel growths may not be taken as a criterion for isomorphism. He said of parallel growths: 'Das Phänomen ist nicht beschränkt auf isomorphe, sondern erstreckt sich auch auf morphotrope Körper. . . . Die ganze Erscheinung hat also nicht den geringsten Wert für chemische Schlussfolgerungen. Es ist weiter nichts als ein Influenzieren auf die Richtung bei der Ausscheidung aus dem flüssigen in den festen Zustand und sehr gut vergleichbar dem sich parallel Orientieren von Eisenstäbchen in der Nähe eines starken Magnetes.'[1] Now, although regular growths of morphotropic substances (or even of substances which are not morphotropic) are known, yet parallel growths as exhibited by sodium nitrate and calcite, potassium perchlorate and barytes—i.e. where the substances are isostructural and the whole orientation is congruent—such parallel growths are never found among morphotropic substances (the felspars being held isomorphous). Further, there is only a very superficial analogy between parallel growths and the action of a magnet on iron-filings, because, although the magnet does orientate the filings in a definite manner, yet the position taken up by the molecules or crystal-units of the filings is not necessarily congruent with the position of the molecules of the orientating magnet.

The author's investigations prove that the case of sodium nitrate and calcite is by no means so uncommon, for the perchlorate-permanganate group stands in the same relation to the barytes group. In both groups an equal number of atoms have arranged themselves in space to form similar structures: that the structures are similar follows from the similarity of cleavage-directions, form, angles, general physical properties, relief of supersaturation, and the formation of parallel growths. Whether these isostructural substances are to be regarded as isomorphous is a matter of definition. The composition is just as analogous as that of $(NH_4)_2SO_4$ and K_2SO_4, or KCN and KCl, $(NH_4)_2Al_2(SO_4)_4.24H_2O$ and $(C_5H_{11}NH_3)_2Al_2(SO_4)_4.24H_2O$, or $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$. Like all isomorphous substances possessing similar molecular volumes, they form parallel growths; they cannot be made to mix because a suitable solvent cannot be found, and if found double decomposition would set in to form substances with quite

[1] Zeits. physik. Chem., 1890, vol. v, p. 460.

different crystal structures. On the other hand, caesium and potassium sulphates do not mix, nor do they form parallel growths, because of the great difference of molecular volume. If the latter salts are still regarded as isomorphous, so must also sodium nitrate and calcite, potassium perchlorate and barytes, if one would be consistent.

The author has recently found that the periodates of silver, lithium, sodium, ammonium, potassium, and rubidium form an isomorphous group crystallizing in the tetragonal system with similar angles to the scheelite group. Using the monomolecular formula for the periodates the similarity of composition becomes obvious: RIO_4 and $CaWO_4$. The growths of the periodates on these minerals will be investigated when suitable mineral specimens have been obtained.

The author's thanks are due to Mr. W. Barlow, for valuable advice on the constitution of a mixed crystal; and also to Professor H. A. Miers, in whose laboratory the above work was carried out.

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Explanation of Plate II.

Parallel (and irregular, fig. 6) growths of crystals of soluble salts on each other:

Fig. 1.—Rubidium chromate on rubidium sulphate (×100).
,, 2. ,, ,, on potassium sulphate (×100).
,, 3. ,, ,, on caesium sulphate (×25).
,, 4. ,, ,, on caesium chromate (×100).
,, 5.—Caesium sulphate on rubidium sulphate (×25).
,, 6.—Irregular growth of caesium sulphate on potassium sulphate (×25).

(From photographs by Mr. A. Robinson.)

On Chlormanganokalite, a new Vesuvian mineral; with notes on some of the associated minerals.

By H. J. Johnston-Lavis, M.D., B. ès Sc., M.R.C.S., F.G.S.
Formerly Professor of Vulcanology in the Royal University of Naples.
And L. J. Spencer, M.A., F.G.S.
Assistant in the Mineral Department of the British Museum.

[Read June 11 and November 12, 1907.]

Occurrence and Chemical Composition.

(By H. J. Johnston-Lavis.)

In 'Nature' of May 31, 1906, the senior author[1] gave a preliminary account of a new Vesuvian mineral, which he had found amongst the products of the eruption of April 1906, and for which he proposed the name chlormanganokalite. It was described as a hydrous chloride of manganese and potassium, occurring as deliquescent crystals apparently rhombohedral in form. A few days later, on June 5, 1906, Professor A. Lacroix[2] described, before the French Academy of Sciences, a Vesuvian mineral which he thought must be identical with chlormanganokalite: he stated it to be an anhydrous chloride of manganese, potassium, and sodium, and he determined the deliquescent crystals to be monoclinic and pseudo-rhombohedral. In a later paper, Professor Lacroix[3] rightly insists upon this identity.

A new analysis has now been made on better selected material, and the new mineral has been submitted to a detailed crystallographic examination. The specimens at our disposal are better than those exhibited in the Muséum d'Histoire Naturelle in Paris.

Towards the latter part of the eruption of April 1906, vast quantities of fragmentary material were shot out from Vesuvius. The earlier ejecta were chiefly 'essential',[4] and date from about half-past twelve (midnight) on April 7–8. These constitute the main portion of the two

[1] H. J. Johnston-Lavis, 'A new Vesuvian mineral.' Nature, 1906, vol. lxxiv, pp. 103–104.

[2] A. Lacroix, 'Les cristaux de sylvite des blocs rejetés par la récente éruption du Vésuve.' Comptes Rendus Acad. Sci. Paris, 1906, vol. cxlii, pp. 1249–1252.

[3] A. Lacroix, 'Les minéraux des fumerolles de l'éruption du Vésuve en avril 1906.' Bull. Soc. franç. Min., 1907, vol. xxx, pp. 219–266.

[4] H. J. Johnston-Lavis, 'On the fragmentary ejectamenta of volcanoes.' Proc. Geol. Assoc., 1886, vol. ix, pp. 421–432, with plate.

strata, 0·20 metre in thickness, at the bottom of the 0·73 metre deposit that partially buried Ottajano. Practically all the rest of that deposit was made up of 'accessory' lapilli. As the axis of the eruption is approached, these materials, and especially the 'accessory', naturally increase in thickness and in the size of their constituents. At Ottajano the blocks rarely attain the size of one's fist, whereas at the foot of the great cone many masses were met with of a cubic metre or more in volume. One large block, on the plain of the Pedimentina almost south of the great cone and over a kilometre from the eruptive axis, I measured and found to be about 27 cubic metres, which would give a weight of over 70 tons.

Two blocks in this direction, each considerably over a cubic metre in volume, yielded the new mineral in association with sylvite. These blocks were seen on examination to be made up of masses of more or less porous scoria, so soldered together that they could be broken up only with difficulty. On breaking up these blocks with dynamite, the cavities between the component masses of scoria were found to be beautifully lined with fine crystals of potassium and sodium chlorides, or the interspaces were completely filled with crystallized chlorides. In certain places, implanted on these crystals, were crystals of chlormanganokalite; and at times the infilling mineral consisted almost entirely of chlormanganokalite.

When fresh, chlormanganokalite consists of splendent, well-shaped crystals with the form of flat rhombohedra, of a lemon- or canary-yellow colour. Exposure to moist air soon impairs their brilliancy, and in a short time they deliquesce to a yellow liquid. Unfortunately the weather was very damp at the time the mineral was discovered, and this, together with an accident to a case full of material, has made the supply available for investigation very limited.

A new analysis, made in May 1907 on nearly a gram of material, gave the following results:—

K	36·34	or	KCl		69·42
Mn	11·52		$MnCl_2$		26·45
Cl	48·13		$MgCl_2$		0·16
Mg	0·04		Na_2SO_4		1·19
Na	0·38		H_2O		1·52
SO_4	0·81		Insoluble		0·71
H_2O	1·52				99·45
Insoluble	0·71				
	99·45				

After deducting magnesium chloride, the atomic ratios are

$$K : Mn : Cl = 0{\cdot}9282 : 0{\cdot}2096 : 1{\cdot}3560 = 4{\cdot}43 : 1 : 6{\cdot}47,$$

corresponding with a formula $4\frac{1}{2}KCl.MnCl_2$. A more probable formula is, however, $4KCl.MnCl_2$, and the slight excess of potassium chloride may be ascribed to the presence of admixed sylvite. The calculated percentage composition corresponding with this formula, $4KCl.MnCl_2$, is:—

K	...	36·91	or	KCl	... 70·33
Mn	...	12·96		$MnCl_2$	... 29·67
Cl	...	50·13			
		100·00			100·00

Calculating the potassium chlorides and manganese chlorides to 100 per cent., the amounts found in the analysis are KCl 72·41, $MnCl_2$ 27·59 per cent.

In October 1906, I found on the northern slopes of the great cone, not far from the edge of the crater, another block, which on being broken open exhibited within its cavities a number of large rhombohedral crystals of a darker yellow (orange) tint. These crystals had obviously been contaminated with some dissolved erythrosiderite, kremersite, &c. The block had, of course, been exposed to fumarolic vapours from the ground on which it lay and to atmospheric weathering for about six months. These crystals showed no polished faces, but were roughened like ground-glass, and they seemed to be made up of minute granular crystals, consisting in fact of pseudomorphs after crystals of chlormanganokalite. On breaking these pseudomorphs open, they were seen to possess a zoned or crusted structure, and to be opaque right to their centre. An analysis of such material would give only uncertain results. Some of these pseudomorphous crystals attain a diameter of a centimetre, and it is unfortunate that they were not found before they had become altered. Even amongst the original specimens, found in April 1906, some of the crystals of chlormanganokalite implanted on the crystals of alkali chlorides have become granular and opaque.

The pseudomorphous crystals in the block found in October 1906 are also, as on the original specimens, associated with sylvite and halite; but in addition there are black, spear-like crystals of haematite, together with pseudomorphous crystals with the form of long, slender square prisms, and possibly some other soluble species. The genesis of the haematite was coincident with that of the other minerals, since it occurs both buried in crusts of them, and projecting from and implanted on their surfaces. Portions of these crusts were lixiviated in water, dried, and

sifted, and the residue treated with a heavy solution of cadmium borotungstate. The heavy particles were collected one by one under the microscope, and analysed with the following results :—

Fe_2O_3	94·79
S	0·43
As	trace
Insoluble in aqua regia .	4·78
	100·00

The insoluble residue represents rock-fragments adherent to the crystals, as was discernible under the microscope. The traces of arsenic are no doubt due to the presence of realgar and orpiment, and the sulphur to those minerals or to native sulphur, all of which occur in the neighbourhood. The crystals of haematite rarely attain a length of 2 mm. A few of the most perfectly developed crystals were selected under the microscope for crystallographic determination (p. 60).

There is little doubt but that chlormanganokalite and its associates are the result of sublimations deposited in the interstices of the fragmentary materials of the cone not far from the chimney of the volcano. By sublimates I do not mean the direct vaporizing of such from the volcanic paste or magma, but rather the production of the minerals by the interaction of different vapours when the latter reach a space where the temperature is sufficiently low to suit the formation of the particular compound. In other words, the minerals have been formed by so-called pneumatolytic action. I was able in 1880 to watch the deposition of well-formed crystals of sylvite and tenorite in such scoria overlying a radial dyke at less than 100 metres from the main chimney of Vesuvius.

No doubt the deposition of such material is constantly going on around the main chimney of the volcano. But it is only by the help of a violent eruption, like that of April 1906, that such deposits are broken up and ejected, and then they are liable to destruction by weathering before being found. An opportunity of examining minerals of this kind therefore but rarely occurs.

The deposition of chlormanganokalite and of the alkali chlorides was contemporaneous, though the new mineral seems to have terminated its deposition later, for it is sometimes superposed on the other minerals.

The formation of these chlorides I infer to have taken place during the state of chronic activity of the volcano, for hydrochloric acid is the dominant emanation in the vapour from the main chimney, and it is only during eruptive paroxysms that sulphurous acid becomes very evident.

Crystallographic and Optical Characters.

(By L. J. Spencer.)

Chlormanganokalite.—The material which I have examined consists of specimens sent by Dr. Johnston-Lavis for the British Museum collection and also of some of the crystals taken from the specimen used by him for analysis. Owing to the rapidity with which the mineral deliquesces in moist air, and especially when exposed to the breath, the specimens had to be examined from behind a glass screen; and when a crystal was placed on the goniometer it was surrounded by a glass tube.

The crystals have the form of simple obtuse rhombohedra, r {100}, sometimes truncated on their median edges by narrow faces of the prism a {10$\bar{1}$}. The faces of the crystals, though at first bright and smooth, soon become moist and dull on exposure to the air, and only approximate measurements could be obtained. On one crystal the angle over the rhombohedral edge was measured in three different zones as 57° 40′, 122° 23′, and 122° 23′; and on another crystal, also in three zones, as 57°, 122° 42′, and 122° 37′. The mean value for the rhombohedral angle rr' is 57° 36′; hence cr=33° 48′, and the axial ratio $a:c$=0·5801.

The crystals measure 2–3 mm. along a rhombohedral edge, and they are sometimes arranged in parallel groups a centimetre across. They are pale wine-yellow in colour, and are transparent with a vitreous lustre. The material is brittle, and shows no cleavage; it breaks with a bright, glassy, conchoidal fracture, which soon becomes dull on exposure to the air. The specific gravity was determined, by floating in methylene iodide, to be 2·31. The hardness is $2\frac{1}{2}$.

An approximate determination of the refractive index was obtained by the method of minimum deviation through a prism formed by the natural faces of the rhombohedron; only a blurred image was seen, and there was no separation into two images; the value in white light was 1·59. The crystals extinguish uniformly when the vibration-directions of the nicols bisect the angles on the rhombohedral faces. By scraping off with a knife the obtuse, polar corners of the rhombohedron, a plate perpendicular to the optic axis was obtained: this showed a good uniaxial cross with no separation of the arms into a hyperbola. The optic sign is positive. Although the section was rather over a millimetre in thickness, the interference-figure showed no rings, only the black cross; so that the double refraction is very low.

From the measurements of the angles and the optical determinations

given above there can be no doubt but that chlormanganokalite is rhombohedral, and not monoclinic (pseudo-rhombohedral) as stated by Lacroix.

Fragments of the crystals when examined in oil under the microscope were seen to contain minute cavities with more or less regular crystal-outlines. These cavities enclose a liquid and a bubble of gas; and in the liquid were seen two kinds of crystals, one kind having the form of cubes. The mineral readily dissolves in a drop of water on a microscope-slide, and while it is being dissolved there is an abundant evolution of minute bubbles of gas. On evaporating the drop of solution, the potassium chloride separates out as skeletal cubes, which are optically isotropic; and on gently warming the slide, the manganese chloride separates as numerous minute birefringent spherulites, which quickly disappear again as the slide cools in moist air.

A fragment of a crystal when heated to 195° C. in an air-oven for half an hour still remained transparent and birefringent. A fragment heated in a bulb-tube gave off a little water, and readily fused to a clear, mobile, yellow liquid; on consolidation the mass is at first white, and when cool reddish in colour, changing again after some time to white.

Sylvite and Halite.—The large and well-developed crystals of sylvite and halite which occur in association with chlormanganokalite have already been described at some length by Professor Lacroix.[1] Shortly afterwards Dr. Johnston-Lavis[2] published an analysis of these cubic crystals, which led to the formula 6KCl.NaCl, and in the belief that this represented a double salt he proposed the name 'chlornatrokalite'. In his later paper Professor Lacroix[3] expresses the opinion that this is evidently a mixture of the two salts.

Specimens labelled 'chlornatrokalite', sent by Dr. Johnston-Lavis for the British Museum collection, were seen on careful inspection to consist of cubes of two kinds, namely, cubes of sylvite (KCl) and cubes of halite (NaCl). The former show a bluish opalescence by reflected light, but are yellowish by transmitted light; under the microscope the yellow colour is seen to be arranged in bands parallel to the faces of the cube. Cavities containing a liquid and a bubble are also arranged in lines parallel to the edges of the cube. The specific gravity was found, by floating a crystal in methylene iodine, to be exactly the same as that

[1] Loc. cit., 1906.

[2] H. J. Johnston-Lavis, 'Another new Vesuvian mineral.' Nature, June 21, 1906, vol. lxxiv, p. 174.

[3] Loc. cit., 1907, p. 242.

(1·99) of sylvite from Galicia, Austria; and a prism bounded by a cleavage-surface and an artificially ground face gave for sodium-light the refractive index 1·491. Finally, the material gave a good violet coloration to the Bunsen-flame. On the other hand, the cubes of halite are colourless and perfectly transparent; they have a specific gravity of 2·15, and a refractive index of 1·547, and they give an intense yellow coloration to the Bunsen-flame.

The crystals of sylvite and halite are intimately and confusedly grouped together, and they appear to have grown simultaneously. On the specimens which I examined the crystals of both salts average $\frac{1}{2}$ cm. along their cubic edges; larger crystals were found, and, according to Lacroix, exceeding 2 cm. across.

The association together of cubes of sylvite and of halite has also been recently described by Dr. F. Zambonini[1] on material from the 1861 eruption of Vesuvius. It may be here remarked that sylvite and halite are only very rarely found at Vesuvius as distinct crystals, saline encrustations of the mixed salts, such as those analysed by A. Scacchi (1875), being much more frequent. As recently pointed out in this magazine,[2] sodium chloride and potassium chloride do not form mixed crystals.

Haematite.—The crystals isolated by Dr. Johnston-Lavis are about 1 mm. in length, and they have the form of acute scalenohedra.[3] The faces are bright, though not perfectly smooth. The following measurements over the three sets of edges prove the form to be $\beta\{31\bar{3}\} = \{24\bar{6}1\}$.

	Measured.	Calculated.
Obtuse polar edge ...	37° 57′ ...	37° 56′
Acute polar edge ...	81 5 ...	81 6
Median edge	25 28 ...	25 33

At the ends of the crystals there are minute faces of the basal pinacoid $c\{111\}$ and the rhombohedron $r\{100\}$. A rhombohedral plane lies in a zone over the median edge of the scalenohedron at 77° 11′ (calculated

[1] F. Zambonini, 'Notizie mineralogiche sull' eruzione Vesuviana dell' Aprile 1906.' Atti R. Accad. Sci. Napoli, 1906, Mem. vol. xiii, pp. 1–40.

[2] T. V. Barker, Min. Mag., 1907, vol. xiv, p. 247; this vol., p. 43.

[3] Crystals of haematite of a scalenohedral habit appear to be of rare occurrence. In the British Museum collection there are two such crystals 'from an island in the Red Sea'; the larger crystal is nearly 3 cm. in length, and the predominating form is $\xi\{13\bar{2}\} = \{2352\}$.

77° 13′) from two scalenohedral planes; the rhombohedron is therefore direct and the scalenohedron inverse.

With these spear-shaped crystals there are a few others of quite a different habit and of rather smaller size ($\frac{1}{2}$ mm. long). They have the form of slender hexagonal prisms, a $\{10\bar{1}\}$, terminated by the basal pinacoid c $\{111\}$; very small faces of the rhombohedron r $\{100\}$ are sometimes also present.

On some twins of calcite; and on a simple method of drawing crystals of calcite and other rhombohedral crystals, and of deducing the relations of their symbols.

By W. J. Lewis, M.A.
Professor of Mineralogy in the University of Cambridge.

[Read January 21, 1908.]

1. Having had occasion recently to draw the twins of calcite, I noticed the advantage of the twin-axes being all placed in the plane of the paper. The representation of the rhombohedron which results from this condition is so unsatisfactory that, obvious as the idea must have been to all crystal draughtsmen, few, if any, seem to have tested the utility of the projection. I desire to point out a few of its advantages.

2. *The rhombohedron.*

Fig. 1 shows a rhombohedron in two positions—the upper one being a plan on the central horizontal (equatorial) plane, and the lower one an elevation with the principal axis VV', the polar edge $V\mu$, and the polar diagonal $V'\mu$ all in the paper. All rhombohedra are projected in the same way: all that need be given is the angle $VV'\mu$, which is the complement of the angle made by a face with the base. Thus, for the fundamental rhombohedron of calcite, shown in fig. 1 and by interrupted lines in figs. 2 and 3, the angle $VV'\mu$ is 45° 23·4′.

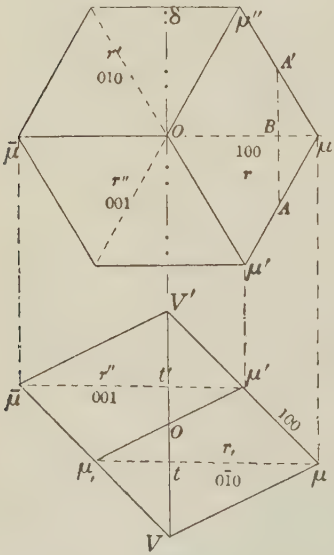

Fig. 1.

The figure is easily drawn. A vertical line being drawn for the principal axis, three equal lengths, $V't'$, $t't$, and tV, are marked off on it. Through V' a second line is drawn at the known angle $VV'\mu$, meeting horizontal lines through t' and t at the points μ', μ. Then clearly $V'\mu' = \mu'\mu$; and

$\mu t = 2\mu' t' = 2\mu_{,} t$. The figure is then completed by drawing the large parallelogram $V'\mu V$, and bisecting it by the median edge $\mu'\mu_{,}$. The points A, B, A' in the plan are projected in the same point in the elevation—midway between μ and μ'. They are important points in the geometry of rhombohedral crystals, and the distinction must be borne in mind.

From the method of drawing, it is clear that the median edge of the two faces shown is in the case of every rhombohedron parallel to the paper, and is projected in a line through the centre, which may be taken as origin. After drawing the fundamental rhombohedron it is advantageous to draw through the median coigns μ faint vertical lines, for the similar coigns of every derived rhombohedron will lie on them, if it is drawn to the same horizontal scale.

The figure being taken to represent the fundamental rhombohedron $\{100\}$ of Miller$=R$ of Naumann, the Millerian axis OX coincides with with $O\mu'$, and the parameter on it may be taken equal to $V\mu$; whilst the axes OY and OZ and the parameters on them are all projected in a line parallel, and equal, to $V\mu_{,}$. The face (100) is projected in the diagonal $V'\mu$; the upper parallelogram is (001), and the lower $(0\bar{1}0)$.

Corollary 1. Now, $\tan V'OX = \tan V'V\mu = \dfrac{\mu t}{Vt} = \dfrac{2\mu_{,}t}{Vt}$.

Also, $$\tan D = \tan V\mu_{,}t = \frac{Vt}{\mu_{,}t}.$$

$$\therefore \quad \tan V'OX \tan D = \frac{2\mu_{,}t}{Vt} \times \frac{Vt}{\mu_{,}t} = 2. \qquad (1)$$

This is the well-known equation which gives the angle made with the principal axis by the polar edge which is taken as axis of reference, when D, the inclination of the face to the base, is known.

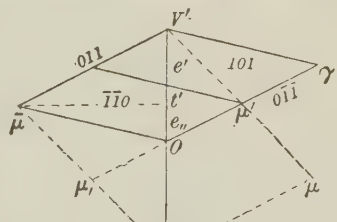

Fig. 2.

Corollary 2. $\{110\} = -\frac{1}{2}R$; fig. 2. Each face of the rhombohedron $\{110\}$ truncates a polar edge of $\{100\} = R$. One of its faces may be taken to pass through the polar edge $V'\bar{\mu}$ of R, and may be projected in any convenient length on this edge. If the length is taken equal to $V'\bar{\mu}$, then t' is the *lower* point of trisection of the length between the apices, and O must be the lower apex of $\{110\}$. Since, to the same horizontal scale,

the length between the apices is one-half of VV', and the face perpendicular to the paper and projected in $O\mu'$, meets the principal axis at the lower apex, the rhombohedron is Naumann's $-\frac{1}{2}R$. The completion of the drawing needs no further explanation.

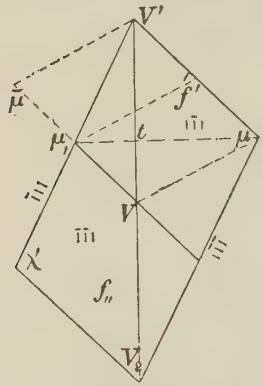

Fig. 3.

Corollary 3. $\{\bar{1}11\} = -2R$; fig. 3. This rhombohedron has each of its polar edges truncated by a face of $\{100\}$. Hence the polar diagonals $V'\mu$, $V'\mu$, may be taken for two of the polar edges of $\{\bar{1}11\}$; and the point t is then the *upper* point of trisection of the length between the apices. The lower apex is at V_2, where $VV_2 = VV'$. The completion of the figure affords no difficulty. The Naumannian symbol is clearly $-2R$; for, to the same horizontal scale, all lengths on the principal axis are doubled, and the faces are turned the opposite way to those of $\{100\}$. Its Millerian symbol is found from the fact that two of its faces are in a zone with (100); hence it is $\{1\bar{1}1\}$ or $\{\bar{1}11\}$.

Corollary 4. Similar constructions will give us further rhombohedra, the faces and edges of which either truncate, or are truncated by, those already drawn; the sign being changed with each truncation, and the length intercepted on the principal axis being successively halved or doubled. Thus we can draw $\frac{1}{4}R$, $-\frac{1}{8}R$, &c. and $4R$, $-8R$, &c.

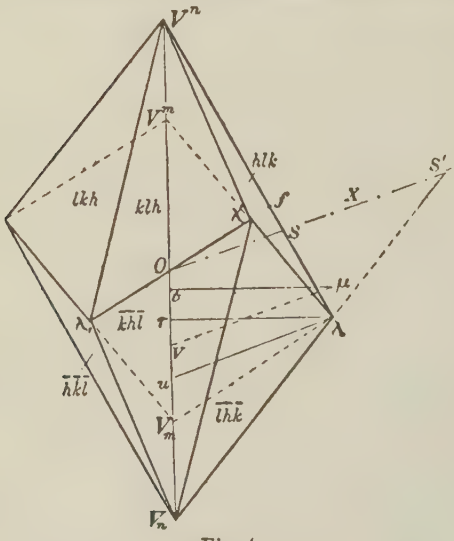

Fig. 4.

Corollary 5. $mR = \{hll\}$. If it is desired to draw this rhombohedron to the same scale as $\{100\}$, lengths mc are marked off from O on both sides of the principal axis to give the apices V^m, V_m. The length V^mV_m is trisected at τ and τ', and horizontal lines are drawn through them to meet at λ, λ', &c. the vertical lines through

μ, μ', &c. The figure is then drawn as in the cases already given. Such a figure is shown by interrupted and continuous lines $\lambda\lambda'$, &c. in fig. 4.

If m is negative, as for instance $-\frac{3}{2}R$, the points λ, λ', &c. on the horizontal lines through τ and τ' must be taken on the opposite sides of the principal axis to those in the figure. We thus have for each value of m two rhombohedra with equal angles, but in which the edges and faces are turned opposite ways. They are sometimes distinguished as *positive* and *negative*; and sometimes as *direct* and *inverse*; the first designations in each case indicating those rhombohedra in which the faces and edges are directed in the same way as those of $R=\{100\}$.

If ϕ is the angle made by the faces of mR with the base, then, from fig. 4,

$$\tan\phi = V^m\tau \div \tau\lambda = \frac{2mc}{3} \div \tau\lambda = \frac{2mc}{3} \div \mu t.$$

But, from fig 1, $\tan D = V't \div \mu t = \frac{2c}{3} \div \mu t.$

$$\therefore \quad \tan\phi = m \tan D. \tag{2}$$

It is clear that, if m and D are known, the angle ϕ can be computed. The rhombohedron can then be drawn to any arbitrary scale by the same process as was followed in drawing the elevation in fig. 1.

We also have (see section 13, corollary 1), $m = \frac{h-l}{h+2l}$. (3)

3. *The scalenohedron*, $mRn=\{hkl\}$; fig. 4.

When the Millerian indices are given, m and n have to be found by the relations proved in section 13:—

$$m = \frac{\theta - 3k}{\theta}, \quad n = \frac{h-l}{\theta - 3k}, \tag{4}$$

where $\theta=h+k+l$, and k is *that* index which occupies the same place in the face-symbol as zero does in the symbol of *that* face of the prism $\{10\bar{1}\}$ which truncates the median edge of the face. Now the prism-face which truncates the rhombohedral edge through O is parallel to the paper, and therefore to the axis of X. Hence zero and therefore k occupy the first place in the symbols of the prism-face and the two scalenohedral faces which intersect in this median edge. The sign of m has to be carefully attended to; for the diagonal $V^m\lambda$ lies to

the right or left of the principal axis according as m is positive or negative. The sign of n is indifferent, for the length nmc has to be marked off on both sides of the origin, and the apices joined indifferently to each median coign λ.

The *auxiliary* rhombohedron mR has to be first drawn in the way described in section 2, corollary 5. The scalenohedral apices V^n, V_n, where $OV^n = nmc$, are then both joined to each median coign λ of mR.

The scalenohedron is said to be direct or inverse according as m is positive or negative. It is clear that the scalenohedron $-mRn$ must have the same angles as mRn; for it only differs in the points λ occupying positions on the opposite sides of the principal axis, but each at the same distance respectively on the lines through τ and τ' as in the case represented in the figure.

4. *The trapezohedron*, $a\{hlk\}$; fig. 5.

It is clear that figures in which the horizontal planes are projected in lines will not be satisfactory, when the base and a number of horizontal lines in, or parallel to, it have to be shown. Hence this method and Naumann's with six equal vertical spaces —both being orthogonal projections with the axis in the paper—are not suitable for hematite, quartz, and similar crystals. But the methods give a fair representation of *one* of the trapezohedra into which the scalenohedron is divided by the omission of faces connected by symmetry-planes, and a fair one of the quartz-twins with inclined axes. The present method has, moreover, the advantage of needing no computation of the lengths of the median edges.

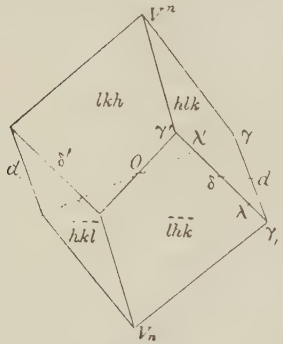

Fig. 5.

Fig. 5 represents on a diminished scale a trapezohedron derived from fig. 4 by the omission of the two central faces and the alternate faces below the paper. The side median edges have both to be extended, and the central edge $\lambda'\lambda$, has to be replaced by a new one through O in which (lkh) meets $(\bar{l}\bar{h}\bar{k})$: this edge is clearly parallel to the scalenohedral edge $V_n\lambda$ of fig. 4. The intersections of this new edge with the extended median edges give two new median coigns (γ' being one), to which polar edges are drawn. Further, the other

median coigns lie on the horizontal lines through this pair, so that two of them are fixed at once. The remaining two lie on the dotted retained median edge, in which the two faces below the paper intersect. The figure is now easily completed.

The relation of the extension of the retained median edges of the scalenohedron is also easily derived from the two figures. The edge $\lambda'\lambda$, in fig. 4 stands parallel to the paper at distance a; and the parallel dotted line $O\gamma$ in fig. 5 is at the same distance below. It is clear therefore that the extension $\lambda'\gamma$ in fig. 5 is double the length $\lambda'f$ in fig. 4. The points γ on this median edge can therefore be easily found; and the horizontal lines through them give those on the two other retained median edges.

5. *The pyramid*, $nP2=\{hkl\}$; fig. 6.

Where $h+l=2k$, or $\theta-3k=0$; and the same rule as to which index is k holds as in the case of the scalenohedron. It is clear that the relation of the indices makes m of equations (4) equal to zero, and there is no auxiliary rhombohedron: the median edges are horizontal.

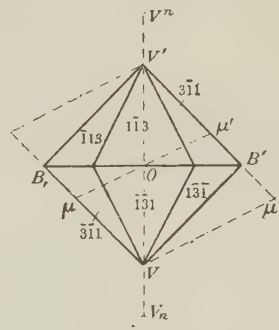

Fig. 6.

Here the connexion between the median coigns in the equatorial plane and the apices for some easily determined pyramid has first to be found. Such a pyramid is that whose alternate polar edges are truncated by faces of the fundamental rhombohedron $\{100\}$. For the diagonals of this rhombohedron give four polar edges of the pyramid, and by joining the points B (only two of which are marked), in which these diagonals meet the central horizontal line, to the opposite apices the figure is completed.

To find the Millerian symbol of the pyramid, fig. 6. Let (hkl) and (hlk) be the two faces whose polar edge $V'B'$ is truncated by (100), projected in $V'\mu$ of fig. 1. Since the three faces are tautozonal, we have by the zone-law (Lewis's 'Crystallography,' p. 40):—

$$l^2-k^2=0, \quad \therefore\ l=-k;$$

for l cannot be the same as k, since two equal indices indicate a rhombohedron, base (111), or prism $\{2\bar{1}\bar{1}\}$. Again, since $h+l=2k$;

$$h=2k-l=3k.$$

The simplest numbers which satisfy these two equations are $3, 1, \bar{1}$; which are therefore the indices of one face. The second face is $(3\bar{1}1)$; and the pyramid is $\{31\bar{1}\}$.

Any other pyramid $nP2$ is found by joining the apices V^n, V_n, to the same points B. The length OV^n has to be found so as to accord with the scale of the pyramid $VB'B$,.

According to the method of projection adopted, the pyramid-edges are drawn through different points in the equatorial plane, and the length intercepted on the principal axis varies accordingly. Thus in Lewis's 'Crystallography', p. 400, the edges pass through points M in which the polar edges of the fundamental rhombohedron meet the equatorial plane. But as shown in p. 372 of the 'Crystallography' the points B are on the lines OM and such that $OB = OM/2$. The pyramid in fig. 6 is therefore drawn to one-half the scale of that in the 'Crystallography', where its symbol is given as $2P2$. Owing to the change of scale it should now be given as $P2$, and the value of n there given, p. 402, must be halved, and to our present scale

$$n = \tfrac{1}{2}\frac{h-l}{h+l}. \qquad (5)$$

Hence for $\{31\bar{1}\}$, $n=1$; and for the pyramid $\{917\}$ shown in the twin, fig. 15, $n=4$.

Naumann draws the pyramid-faces through the points A (see plan, fig. 1) at unit distance on the dyad axis to which the edge is perpendicular. The angle between OA and OB in fig. 1 being 30°, the line OB is in that case met at distance $OA \sec 30° = OB \sec^2 30° = \frac{4}{3}OB$. His n is therefore $\frac{4}{3}$ of that given by equation (5). The two other dyad axes $O\delta$ and OA' are met at double the distance intercepted on the first, OA; and hence the symbol $nP2$. Naumann's value of n is found in section 13, corollary 2.

6. *To draw combinations of a hexagonal prism and a rhombohedron;* figs. 7 and 8.

If the prism is $\{10\bar{1}\}$ (fig. 7), its faces truncate each a median edge of every rhombohedron, and the drawing is made in the same way for all of them. The rhombohedron, say $\{110\}$, is first drawn as in section 2, corollary 2; and the figure is then completed by drawing equal vertical lines through the median coigns: the lower ends of these lines giving points through which the lower faces pass.

When the hexagonal prism is $\{2\bar{1}\bar{1}\}$ (fig. 8), two of the faces are projected in the vertical edges marked $2\bar{1}\bar{1}$ and $\bar{2}11$. The drawing is similar whatever the rhombohedron; and this is first drawn. Let it be $\{110\}$. The faces (101) and $(1\bar{2}1)$ meet in a line parallel to the horizontal diagonal of (101), i. e. a line like AA' of the plan in fig. 1. The face $(\bar{1}\bar{1}2)$ meets (011) in the original line in which this face is projected; but it meets (101) in a new line which passes through a point in which a horizontal line through g meets the projection of (011); g being the point in which $(2\bar{1}\bar{1})$ meets the polar edge. *In this and all combinations involving a rhombohedron, the coigns at each end are of two kinds, similar*

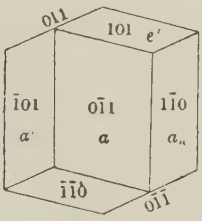

Fig. 7.

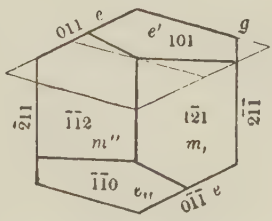

Fig. 8.

ones lying in a horizontal plane. Hence, if the position of one coign of a kind is found, the other like ones are found by drawing a horizontal line through the known coign to intersect lines on which the coigns lie. The completion of the figure is now obvious.

7. *To draw combinations of a scalenohedron, the prism* $\{2\bar{1}\bar{1}\}$, *and a rhombohedron;* figs. 9 and 10.

The method being the same whatever the scalenohedron, we select for illustration $\{20\bar{1}\} = R3$; for it gives a common crystal of calcite. This is first drawn as already explained, $\{100\}$ being the auxiliary rhombohedron. We then introduce the prism-faces, which meet at O, A, $A_{,}$, the middle points of the median edges. Through A and $A_{,}$ vertical lines are drawn, in which $(2\bar{1}\bar{1})$ and $(\bar{2}11)$ are foreshortened. These lines meet the polar edges at points which fix the two sets of horizontal lines on which like coigns lie. Each such coign is joined to the nearest pair of middle points, and fig. 9 is completed.

When the prism-edges are long, as in fig. 10, vertical lines of the required length are drawn through O, A, $A_{,}$; and the lower part is then obtained by drawing lines, parallel to those forming the lower part of

fig. 9, through an apex displaced to the same extent and through new points on a horizontal line as if they were O, A, and A_1.

In fig. 10 the rhombohedron $e\{011\}$ is also represented; and the method of introducing the faces is the same for every rhombohedron. The scalenohedron and prism having been first drawn in the manner just described, through each of two points equally distant from the scaleno-

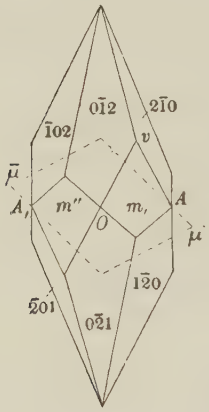

Fig. 9.

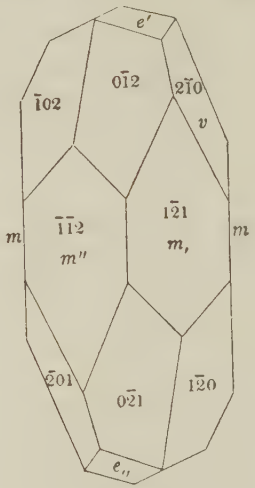

Fig. 10.

hedral apices two lines are drawn parallel respectively to the polar diagonal and edge of the rhombohedron which lie in the paper. These lines bound the complete figure; and also determine, by their intersection with the polar scalenohedral edges, the points through which horizontal lines have to be drawn so as to get the remaining coign of each of the two faces seen. The figure gives a fair representation of crystals common in Cumberland.

Calcite Twins.

8. The drawing of these twins is now easy, and the pictures are fairly satisfactory. Fig. 11 shows the common 'dog-tooth' twin of Derbyshire, having (111) for twin-face; i. e. face of association the base, and axis of rotation the principal axis. The way of drawing the figure is obvious from comparison of figs. 4 and 9.

The method does not give a satisfactory picture of a twin in which the forms are the prism $\{2\bar{1}\bar{1}\}$ with a rhombohedron; nor is it satisfactory

for the similar twins of dolomite, in which the form is {100}, and the one individual is associated with the other partly along the base and partly along prism-faces.

9. In drawing twins with inclined principal axes the diagram of the simple crystal is divided by a line parallel to the diagonal in which the twin-face is projected, and perpendiculars to this line are drawn across it through each coign which is shown. Points on these perpendiculars at the same distance from the section-line as the coigns are then marked. These points are joined to one another and to the points in which the section-line is cut by edges of the simple crystal, so that the rotated or reflected portion is the symmetrical duplication of the first. The method has the advantage that, after the twin has been drawn, the figure can be turned round so as to place the twin-face vertical and the twin-axis horizontal.

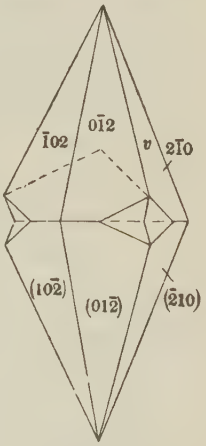

Fig. 11.—Calcite twinned on $c(111)$.

10. *Twin-law* $r(100)$. Fig. 12 shows a twin according to this law. The forms are $\{2\bar{1}\bar{1}\}$ and $\{101\}$. The twins are fairly common in Cumberland, and are often very flat from the small width of the face $m(2\bar{1}\bar{1})$ and the large extension of $(1\bar{2}1)$.

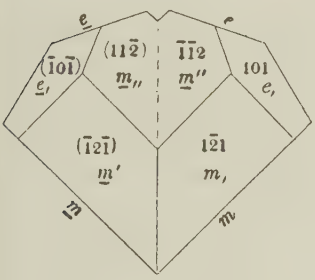

Fig. 12.

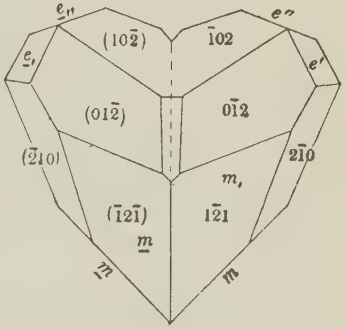

Fig. 13.

Calcite twinned on $r(100)$.

Fig. 13 shows a twin according to this law produced from fig. 10. Fig. 14 shows the common 'butterfly-twin': it has been obtained from fig. 13 by largely developing the faces $(0\bar{1}2)$ and $(02\bar{1})$ which meet in a line parallel to the polar edge $V\mu$ of fig. 1. After they had been

drawn the figures have been turned round, so as to put the twin-face upright.

11. *Twin-law e* (011). This twin-law is that commonly observed in thin twin-lamellae. It is somewhat rare in distinct well-grown twins, but the Cambridge Museum has two rather remarkable specimens. The one represented in fig. 15 occurs in tabular twins of fair, and nearly equal

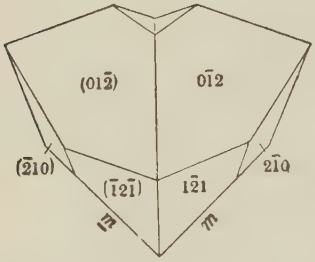

Fig. 14.
Calcite twinned on r(100).

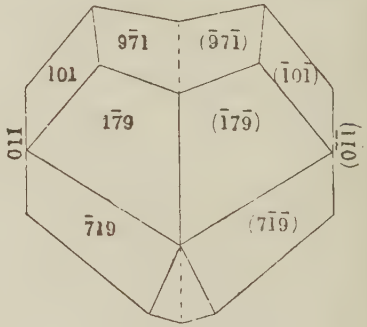

Fig. 15.
Calcite twinned on e(011).

thickness—dimensions varying from $1\frac{1}{4}$ to 2 inches across by $\frac{1}{2}$ to 1 inch thick. Their surfaces have a thin crust of pitted and frosted calcite, which gives no reflected image: they are associated with some decomposing marcasite, and one has the cast apparently of a cubic face of fluor crystal. At first sight the forms seem to be those shown in fig. 7; but close inspection of the apparent prism shows that the edges are not parallel, although nearly so. As one of the twins was slightly broken, it was possible to get from a fragment the approximate angles of one of the faces to the three cleavages by gumming a piece of cover-glass to the rough face. The observed angles, and those computed for {917} by formulae (25) in this Magazine, vol. xii, p. 339, are given in the following table:—

		Computed.		Measured.
$\lambda = 100 \wedge 917$	...	41° 42′	...	—
$\bar{1}00 \wedge$ „	...	138 18	...	138° 7′
$\mu = 010 \wedge$ „	...	81 13	...	81 21
$0\bar{1}0 \wedge$ „	...	98 47	...	98 33
$\nu = 001 \wedge$ „	...	116 12	...	116 20
$00\bar{1} \wedge$ „	...	63 48	...	63 41

For the determination of the face-symbol from measurements of the

angles λ, μ, ν, equations (25) can be easily transformed to give the following:—

$$\frac{h-k}{k-l}=\frac{\cos\lambda-\cos\mu}{\cos\mu-\cos\nu}=\frac{\sin\frac{\lambda+\mu}{2}\sin\frac{\lambda-\mu}{2}}{\sin\frac{\mu+\nu}{2}\sin\frac{\mu-\nu}{2}}. \qquad (6)$$

Introducing the observed values of the angles, we find by tables of natural, or logarithmic, sines and cosines:—

$$\frac{h-k}{k-l}=1, \text{ very nearly};$$

$$\therefore\ h-2k+l=\theta-3k=0;$$

and the form is a bipyramid. The indices are then easily found from any pair of equations (5).

The angles λ, μ, ν, made by any face with the axial planes of a rhombohedral crystal are connected with the angle $D=100\wedge 111$ and the angle, CP, between that face and the basal plane, by the following expression (which may be readily deduced in a manner similar to that in Lewis's 'Crystallography', p. 355):—

$$\cos\lambda+\cos\mu+\cos\nu=3\cos D\cos CP. \qquad (7)$$

From equations (25) we can now obtain the following equations, which render easy the determination of h, k, l:

$$\frac{h}{\cos\lambda\cos D-\cos CP\cos a}=\frac{k}{\cos\mu\cos D-\cos CP\cos a}$$
$$=\frac{l}{\cos\nu\cos D-\cos CP\cos a}=\frac{\theta}{(1-\cos a)\cos CP}; \qquad (8)$$

a being the angle over the polar edge of $\{100\}$.

The second twin, of which there are three or four individuals, occurs on a specimen from the lead mines of Seven Churches, Co. Wicklow. They are very thin; and the largest are about $1\frac{1}{4}$ inches across by only $\frac{1}{6}$th of an inch in the thickest part. Most of them are now detached, as they were very loosely attached by the edge to the matrix. The form is the scalenohedron $\{13.\ 0.\ \overline{11}\}=R12$, a form which Irby[1] gives as doubtful. Owing to the edges being partially broken along the cleavages, it was possible to measure the several zones; and the angle $(100):(13.\ 0.\ \overline{11})$ has a mean value of 46° 21′ (the extremes in different zones being 46° 18′ and 46° 23′). The computed angle is 46° 23′. Several of the faces, and especially the widely extended ones, gave more than

[1] J. R. McD. Irby, 'On the crystallography of calcite.' Inaug.-Diss., Bonn, 1878.

one image. These twins are associated with very long, slender crystals, which proved on measurement to be the simple scalenohedron $\{13.0.\overline{11}\}$.

As is common in twins according to this law which are known to me, there is in parts an overlapping of one individual over the other in both the twins described.

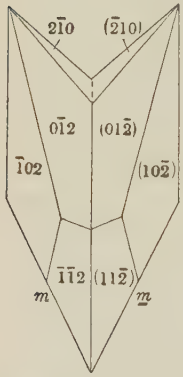

Fig. 16.—Calcite twinned on $f(\bar{1}11)$.

12. *Twin-law* $f\{\bar{1}11\}$. Twins according to this law are rather uncommon. They sometimes occur in Cumberland in crystals in which the prism $\{2\bar{1}\bar{1}\}$ is largely developed; and they have been found in Somersetshire[1] in rough crystals which are a combination of $\{20\bar{1}\}$ with $\{2\bar{1}\bar{1}\}$. A twin of this latter kind is shown in fig. 16. To draw it we have only to divide a crystal, like that shown in figs. 9 or 10, by a line parallel to $V_2\mu$ of fig. 3, and to erect perpendiculars through the coigns to this line.

13. The principle of the drawings lends itself to the determination of certain numerical relations; but not to the computation of angles or the converse. We shall illustrate the way in which the drawings may be useful, by deducing the relations between Naumann's and Miller's symbols for the scalenohedron and other forms.

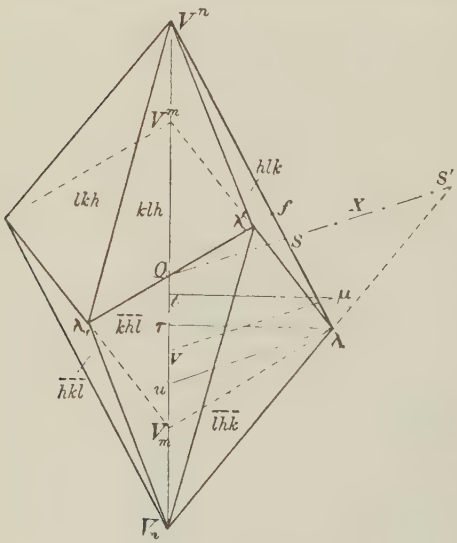

Fig. 4 (repeated).

To determine in the scalenohedron, $mRn=\{hkl\}$, *the relations between* m *and* n *and the indices,* h, k, l *of one of its faces.*

It is easy to see that the Millerian symbols inscribed on the scalenohedral faces are consistent. For two faces meet in the polar edge $V^n\lambda$ and intersect OX at S (fig. 4), where $OS=V\mu/h$. If the face above the paper is denoted by (hlk), that which is symmetrical to it and behind the paper is (hkl), and the parallel face (that to the left and bottom) is $(\bar{h}\bar{k}\bar{l})$.

[1] H. L. Bowman, Min. Mag., 1903, vol. xiii, p. 329.

Draw $u\lambda$ parallel to $V\mu$ and OX to meet the principal axis at u, then $u\lambda = V\mu$; and $Vu = \mu\lambda = t\tau = \frac{m-1}{3}c$.

Also, $$Ou = OV + Vu = \frac{m+2}{3}c.$$

From the similar triangles OSV^n, $u\lambda V^n$, we have

$$h = \frac{V\mu}{OS} = \frac{u\lambda}{OS} = \frac{uV^n}{OV^n} = \frac{OV^n + Ou}{OV^n}$$

$$= \frac{mnc + \frac{m+2}{3}c}{mnc} = \frac{m+2+3mn}{3mn}. \qquad (9)$$

Again, the two faces which meet in $V_n\lambda$ have $-l$ for first index; i. e. $OS' = -\frac{V\mu}{l}$. Hence from the similar triangles $OS'V_n$, $u\lambda V_n$, we have

$$-l = \frac{V\mu}{OS'} = \frac{u\lambda}{OS'} = \frac{uV_n}{OV_n} = \frac{OV_n - Ou}{OV_n}$$

$$= \frac{mnc - \frac{m+2}{3}c}{mnc} = \frac{3mn-m-2}{3mn};$$

$$\therefore \quad l = \frac{m+2-3mn}{3mn}. \qquad (10)$$

Again, the two faces (klh) and (khl) will, if produced, meet in a line in the paper parallel to $O\lambda'$; and it will therefore meet OX on the *negative* side in a point E (not shown). Now $O\lambda'$ is parallel to $V_m\lambda$; consequently the triangle OV^nE is similar to $u\lambda V_m$.

$$\therefore \quad -k = \frac{V\mu}{OE} = \frac{u\lambda}{OE} = \frac{uV_m}{OV^n} = \frac{OV_m - Ou}{OV^n}$$

$$= \frac{mc - \frac{m+2}{3}c}{mnc} = \frac{2(m-1)}{3mn};$$

$$\therefore \quad k = \frac{2(1-m)}{3mn}. \qquad (11)$$

From equations (9), (1), and (11) we have

$$\frac{h}{m+2+3mn} = \frac{k}{2(1-m)} = \frac{l}{m+2-3mn} = \frac{1}{3mn}. \qquad (12)$$

Hence we have

$$\frac{h+l-2k}{h+k+l} = \frac{2(m+2)-4(1-m)}{6} = m. \qquad (4^*)$$

and $$\frac{h-l}{h+l-2k} = \frac{6mn}{2(m+2)-4(1-m)} = n. \qquad (4^{**})$$

Also $$mn = \frac{h-l}{h+k+l}. \qquad (13)$$

As has already been said, the sign of m has to be carefully attended to; that of n is immaterial.

Corollary 1. When $n=1$, the scalenohedron coincides with the auxiliary rhombohedron mR. From equation (4**), it follows that $k=l$. Hence from equation (4*),

$$m = \frac{h-l}{h+2l}. \qquad (3^*)$$

Corollary 2. For the pyramid n_1P2, the median edges of the scalenohedron, which pass through points A on the dyad axes at distance a from the origin, become horizontal, and the height mc of the auxiliary rhombohedron is zero. Hence $m=0$; i. e. $h+l-2k=0$. (14)

But the distance OV^n is finite. In the pyramid it is denoted by n_1c; and in the scalenohedron mnc: $\therefore n_1=mn$.

Therefore from equation (13)

$$n_1 = mn = \frac{h-l}{h+k+l}.$$

Introducing the value of k from (14),

$$n_1 = \frac{2}{3}\frac{h-l}{h+l}. \qquad (15)$$

This is the relation corresponding to Naumann's way of drawing the pyramid; for, as stated in section 5, he draws each horizontal edge through a point A on the perpendicular dyad axis to meet each of the two adjacent dyad axes at a distance $2a$. The scale in drawing fig. 6 is $\frac{3}{4}$ of his, and consequently n of section 4 is given by

$$n = \tfrac{3}{4}n_1 = \tfrac{1}{2}\frac{h-l}{h+l}. \qquad (5^*)$$

The relation (5) can easily be deduced from fig. 6 by drawing the axis OX and a parallel line through B, and employing similar triangles in a manner corresponding exactly with that by which the scalenohedral relations have been obtained.

14. As already pointed out in section 4, $\lambda'\gamma$ (on the dotted line $O\gamma$ in fig. 5) is equal to $2\lambda' f$ of fig. 4, when both figures are drawn to the same scale. We can now find the extension in terms of the indices. Now $O\lambda'$ and $V_m\lambda$ being parallel edges of mR, $O\lambda' = \frac{1}{2}V_m\lambda$.

Then by the similar triangles V^nOf, $V^nV_m\lambda$, fig. 4, we have,

$$\frac{Of}{V_m\lambda} = \frac{OV^n}{V^nV_m} = \frac{OV^n}{OV^n + OV_m} = \frac{mnc}{mnc+mc} = \frac{n}{n+1}. \tag{16}$$

$$\therefore \quad \frac{\lambda' f}{V_m\lambda} = \frac{Of - O\lambda'}{V_m\lambda} = \frac{Of}{V_m\lambda} - \frac{O\lambda'}{V_m\lambda} = \frac{n}{n+1} - \frac{1}{2} = \frac{n-1}{2(n+1)}.$$

$$\therefore \quad \lambda'\gamma = 2\lambda' f = \frac{n-1}{n+1} V_m\lambda = \tfrac{1}{2}\frac{n-1}{n+1} O\lambda'. \tag{17}$$

From equation (4) we also have

$$\frac{n-1}{n+1} = \frac{h-l-\theta+3k}{h-l+\theta-3k} = \frac{k-l}{h-k}.$$

$$\therefore \quad \lambda'\gamma = \frac{k-l}{2(h-k)} O\lambda'. \tag{18}$$

Care must be taken in using (18) to attend to which of the three indices is k.

On Strüverite and its relation to Ilmenorutile.

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[Read March 19, 1907, and January 21, 1908.]

THE mineral strüverite occurs[1] as a rare accessory constituent of the pegmatite which is found in large detrital masses in the neighbourhood of Craveggia (Val Vigezzo, northern Piedmont), namely on the Piano dei Lavonchi and in other localities on the eastern slope of the mountain across which runs the road from Vasca to the Alp Marco. In this pegmatite Professor G. Spezia[2] in 1882 noted the occurrence of beryl, and two years later Professor G. Strüver[3] that of columbite, a mineral which had not hitherto been found in the Alps. Still later, notices of other rare minerals from the pegmatite were published by Professor A. Piccini[4] and Professor A. Cossa[5]. One of the minerals noted by Piccini is probably strüverite, but owing to paucity of material, he was unable to characterize it exactly.

The new mineral occurs in small crystalline masses embedded in the quartz and felspar of the pegmatite. It is present in very small amount, and it was with great difficulty that sufficient material could be isolated for the physical and chemical investigation, the results of which are given in the present paper.

[1] A detailed description of the occurrence and of the physical characters of strüverite has been published by one of us: Ferruccio Zambonini, 'Strüverite, un nuovo minerale.' Rend. R. Accad. Sci. Napoli, 1907, ser. 3, vol. xiii, pp. 35–41. The details of the chemical examination are given for the first time in the present paper.

[2] G. Spezia, Atti R. Accad. Sci. Torino, 1882, vol. xvii, p. 769.

[3] G. Strüver, Rend. R. Accad. Lincei, Roma, 1884, ser. 4, vol. i, p. 8.

[4] A. Piccini, Rend. R. Accad. Lincei, Roma, 1886, ser. 4, vol. ii, sem. 2, p. 46.

[5] A. Cossa, Gazz. chim. ital., 1887, vol. xvii, p. 31.

Crystallographic and physical characters of strüverite. (F. Z.)

In colour the mineral is iron-black: its powder is grey-black. The lustre is brilliant on a freshly fractured surface. The hardness is 6. The specific gravity was determined on two different samples as 5·54 (F.Z.) and 5·59 (G.T.P.). The mineral is opaque even in the thinnest flakes: it is infusible before the blowpipe.

Well-developed crystals are rare and generally very small. The largest crystal found measures 8 mm. in its longest direction: it is bipyramidal in habit (fig. 1), and shows the forms $a\{100\}$, $m\{110\}$, and $s\{111\}$. Of the much smaller crystals, some are like the large one, while others are of prismatic habit (fig. 2). Crystals of this second type are sometimes tabular parallel to $a\{100\}$ (fig. 3). Of frequent occurrence are crystals elongated along the edge $s:s = [(111):(1\bar{1}1)]$; most of these appear to be twins on a face of the form $\{101\}$, like the well-known twins of ilmenorutile, tapiolite, and mossite, and also of rutile from certain localities.

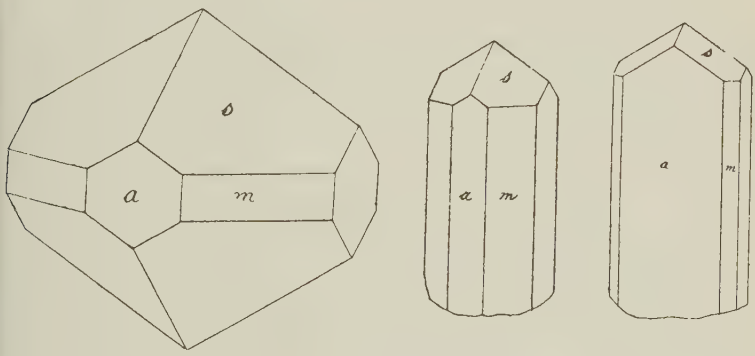


Fig. 1. Fig. 2. Fig. 3.

Crystals of strüverite.

The pyramid-angle $(111):(\bar{1}11)$ could be measured with great exactness: the values obtained on different crystals are:—

$$56°\,54',\quad 56°\,55',\quad 56°\,56',\quad 56°\,57',\quad 57°\,2'.$$

From the mean value, 56° 57′, was calculated the axial ratio—

$$a:c = 1:0{\cdot}6456.$$

The following table gives the measured and the calculated angles:—

	Limits of measured angles.	Number of measurements.	Mean.	Calculated.
ss' = (111) : ($\bar{1}11$)	56° 54′ – 57° 2′	5	56° 57′	—
as = (100) : (111)	61 19 – 61 46	7	61 33	61° 31½
ms = (110) : (111)	47 31 – 47 41	2	47 36	47 36¼
ss'' = (111) : ($\bar{1}\bar{1}1$)	—	1	84 48	84 47½
aa' = (100) : (010)	89 57 – 90 8	2	90 2½	90 0
am = (100) : (110)	44 57 – 45 2	6	45 1	45 0
mm' = (110) : ($1\bar{1}0$)	89 51 – 90 6	3	89 59	90 0

The crystallographic constants of strüverite approximate very closely to those of rutile, tapiolite, mossite, and ilmenorutile.

Chemical composition of strüverite. (G. T. P.)

A preliminary examination made by one of us (F. Z.) had shown the presence of niobic and tantalic acids, together with titanic acid, oxide of iron, and traces of oxide of manganese : colorimetric determinations, moreover, had indicated that the titanic acid was present to the amount of about 44 per cent.

For the two quantitative analyses only about a gram of material, apparently perfectly pure and homogeneous,[1] was available. The quantitative analysis of the mineral presented considerable difficulty; the following description of the methods employed is therefore given in some detail.

It is well known that the methods at present available for the separation of niobic, tantalic, and titanic acids are very imperfect. C. H. Warren[2] has shown that the volumetric method by reduction with zinc is inaccurate, and that in the usually employed method of fusion with acid sulphate of potassium and leaching out with water, a certain amount of tantalic and niobic acids may pass into solution with the titanic acid. In the course of the present investigation it has been found that the error due to the latter cause is much more considerable than has hitherto been conceived. In the presence of such large amounts of titanic acid as occur in strüverite (40 per cent.), the greater part of the tantalic and niobic acids may in this way pass into solution. Further, if the melt with acid sulphate of potassium be treated, instead of with water, with a dilute (5 per cent.) solution of sulphuric acid

[1] On the homogeneity of the mineral see the previous paper by Zambonini, loc. cit., p. 44.

[2] C. H. Warren, Amer. Journ. Sci., 1906, vol. xxii, p. 520, or Chem. News, 1906, vol. xciv, p. 298.

(as is necessary when the titanic acid is to be subsequently colorimetrically determined), practically the whole of the tantalic and niobic acids passes into solution with the titanic acid.

In both analyses the mineral was fused with acid sulphate of potassium and the melt treated with water only slightly acidified with sulphuric acid. The insoluble residue of niobic and tantalic acids was collected and tested in the usual way with ammonium sulphide, &c., for tin and tungsten, and with hydrofluoric acid for silica. After the removal of the tantalic and niobic acids, the titanic acid with iron, &c., in the filtrate was twice precipitated by ammonia. The complete solubility of this precipitate in hydrofluoric acid showed the absence of the yttria and ceria earths and thoria. In the first analysis, for the separation of the iron, the precipitate with ammonia was converted into sulphate and the solution was poured into a concentrated solution of ammonium carbonate containing ammonium sulphide. The separation was not quite perfect, for a little iron was later volumetrically determined in the precipitate containing the titanic acid, and a little titanic acid was also found in the sulphide of iron and colorimetrically determined.

In the second analysis the titanic acid, &c., was separated from iron by precipitation with sodium thiosulphate. In this case also the separation was not quite complete and a little iron retained in the precipitate of titanic acid was subsequently determined by precipitation with ammonia and ammonium sulphide in a solution containing tartaric acid. As it was feared that some niobic and tantalic acid had passed into solution with the titanic acid after the fusion of the mineral with acid sulphate of potassium, the precipitate obtained with sodium thiosulphate was ignited and then re-fused with acid sulphate of potassium. On treating the melt with cold water, a further insoluble residue was obtained and was added to the niobic and tantalic acids separated after the first fusion of the mineral. The combined insoluble residues were brought into solution in hydrofluoric acid, and the tantalic and niobic acids were separated by Marignac's method. They were found to be present in approximately equal parts by weight. Finally they were converted into sulphates, and any titanic acid which had been retained in the insoluble residues was determined colorimetrically.

The filtrate, containing the bulk of the titanic acid and presumably free from niobic and tantalic acids, was made up to 500 c.c. with dilute (5 per cent.) sulphuric acid, and in portions of this solution the titanic acid was colorimetrically determined. The results showed that titania was not the only oxide present in the solution. The other oxide,

amounting to about 28 per cent. of the mineral, was at first supposed to be zirconia, and this idea appeared to be confirmed by the fact that portions of the solution from which most of the sulphuric acid had been removed gave a good precipitate with hydrogen peroxide and an alkali phosphate.[1] Further investigation, however, showed that zirconium was absent, and that the supposed zirconia really consisted of niobic and tantalic acids which had passed into solution with the titanic acid as indicated above (p. 80).

The absence of zirconium was proved by the failure to obtain the characteristic needles of the oxychloride[2] and by the fact that portions of the 500 c.c. solution, after removal of the excess of acid, were wholly precipitated by long-continued boiling. Moreover, it was found that slimy precipitates similar to those obtained in the case of strüverite also resulted by the addition of hydrogen peroxide and an alkali phosphate to sulphuric acid solutions of niobic and tantalic acids, and even to solutions of titanic acid if they contained little free acid and were allowed to stand for some time. In the latter case similar precipitates were obtained by the use of an excess of acetate instead of a phosphate with the hydrogen peroxide. As these precipitates form, the deep colour at first produced by the hydrogen peroxide gradually fades, but is restored on the addition of excess of sulphuric acid. These precipitates with titanic acid consist of the phosphate and acetate of the higher oxide of titanium, which, it was subsequently found, have been quite recently described by P. Faber.[3] The slimy precipitates obtained with solutions of niobium and titanium are very different in character from the gelatinous precipitate produced by the addition of hydrogen peroxide and an alkali phosphate to solutions of zirconia. In the case of zirconia it was incidentally found, in accordance with the experience of Hillebrand and others,[4] that no precipitate of the higher oxide could be obtained by the addition of pure, dilute hydrogen peroxide to acid and moderately dilute solutions of the sulphate. It was only by the use of the pure and

[1] The idea that zirconium was present as an essential constituent of the mineral was unfortunately communicated to Dr. Zambonini before the completion of the analyses, and was published by him in the paper to which reference has already been made (see footnote, p. 78). The chemical data there given therefore need correction.

[2] R. Ruer, Zeits. anorg. Chem., 1905, vol. xlvi, p. 456.

[3] P. Faber, 'Ueber das Wesen des sechswertigen Titans.' Zeits. anal. Chem., 1907, vol. xlvi, pp. 277–291.

[4] W. F. Hillebrand, 'The analysis of silicate and carbonate rocks.' United States Geol. Survey, 1907, Bull. no. 305, p. 119.

undiluted 'perhydrol' of Merck in large excess[1] to fairly concentrated solutions that a precipitate could be obtained. With commercial hydrogen peroxide, however, precipitates were obtained even in acid and dilute solutions, owing to the impurity of phosphate invariably present.

The investigation had so far proved the absence of zirconium, and suggested the presence of niobic and tantalic acids in the solution containing the bulk of the titanic acid. The presence of niobium was confirmed by fusing with potassium carbonate the precipitate obtained by means of hydrogen peroxide and a phosphate, and treating the water-extract with phosphoric acid and zinc dust, according to a method recently described by W. B. Giles.[2] A brown coloration showed the presence of niobic acid. Another portion of the 500 c.c. solution (see p. 81) was then tested for tantalum by precipitating with ammonia, dissolving the precipitate in hydrofluoric acid and treating the solution by the method of Marignac for the separation of tantalum and niobium. A good crop of fine needles of the double fluoride of tantalum and potassium was obtained. These needles and the filtrate from them were decomposed by sulphuric acid, and in each solution (freed from fluorine) the titanic acid was determined colorimetrically. The total weight of $Ta_2O_5 + TiO_2$ obtained from the needles was 0·0483 gram, of which 0·0212 consisted of titanic acid; while the total weight of $Nb_2O_5 + TiO_2$ from the filtrate amounted to 0·0801 gram, of which 0·0524 consisted of titanic acid. The tantalic and niobic acids were therefore present in about equal parts by weight.

The following experiments were then made in order to test the solubility of niobic and tantalic acids in presence of excess of titanic acid :—

(1) A mixture of columbite (from Moss, Norway) and tantalite (from Greenbushes, Western Australia) was made in the following proportions :—

tantalite, 0·1591 gram.
columbite, 0·1653 „

This was fused with acid sulphate of potassium, and the melt was treated with a 5 per cent. solution of sulphuric acid. An insoluble residue of niobic and tantalic acid weighing 0·2553 gram, and thus equivalent to about 79 per cent. of the mixture, was obtained.

[1] When a few drops only of 'perhydrol' are added to a concentrated solution of zirconium sulphate, the precipitate first formed dissolves on shaking, and a permanent precipitate only results after the addition of a considerable excess of the hydrogen peroxide.

[2] W. B. Giles, Chem. News, 1907, vol. xcv, pp. 1 and 37.

(2) A mixture of approximately the same weights of columbite and tantalite was taken, and to it was added an amount of rutile (from Passau, Bavaria) corresponding to about 40 per cent. (as in strüverite) of the total mixture, as follows :—

tantalite, 0·1733 gram.
columbite, 0·1487 „
rutile, 0·2034 „

On fusion with acid sulphate of potassium and treatment of the melt with a 5 per cent. solution of sulphuric acid as in (1), *practically the whole passed into solution.*

(3) Another mixture was made of tantalite, columbite, and rutile in approximately the same proportions as in (2), thus :—

tantalite, 0·1626 gram.
columbite, 0·1506 „
rutile, 0·1905 „

In this case the melt from the fusion with acid sulphate of potassium was treated with cold water alone, without sulphuric acid. An insoluble residue weighing 0·2062 gram was obtained, and of this as much as 0·0563 gram was colorimetrically determined to consist of titanic acid. The residual 0·1499 gram of niobic and tantalic acids corresponded only to about 30 per cent. instead of the theoretical 50 per cent. of the mixture.

The results of the analyses of strüverite are as follows :—

	I.	II.	Mean.	Molecular ratios.
TiO_2	41·09	41·32	41·20 [1]	0·515
Nb_2O_5 } Ta_2O_5 }	46·94 [2]	46·98	23·48 [3]	0·088
			23·48	0·053
FeO	11·15	11·62	11·38	0·158
MnO	trace	—	trace	
CaO	0·51	—	0·51	
MgO	0·17	—	0·17	
			100·22	

Weight of material used in I, 0·4508; in II, 0·4843 gram. The simplest formula suggested by the numbers is $FeO.(Ta,Nb)_2O_5.4TiO_2$, for which the theoretical composition is as follows :—

[1] A third determination of the titanic acid, made on 0·0747 gram of material, gave the number 40·72.

[2] Of this percentage of niobic and tantalic acids, 27·85 passed into solution with the titanic acid.

[3] The experiments described on pp. 81, 83 indicate that the tantalic and niobic acids are present in about equal parts by weight.

TiO_2	...	...	44·03
Ta_2O_5	...	...	23·03
Nb_2O_5	...	...	23·03
FeO	...	...	9·91
			100·00

The molecular ratios, however, correspond more exactly to a formula $3Fe(Ta,Nb)_2O_6.10TiO_2$, and the mineral is perhaps to be regarded (see later, p. 88) as a solid solution of the rutile molecule (TiO_2) and the tapiolite or mossite molecule $Fe(Ta,Nb)_2O_6$. The specific gravity of such a mixture in proportions by weight of 2 : 3 (corresponding to the above analyses), if we take the specific gravity of rutile as 4·18 and that of mossite as 6·45, would be 5·54, which approximates closely to the specific gravity, 5·59, of the material analysed.

Chemical composition of ilmenorutile. (G. T. P.)

The mineral ilmenorutile, with which strüverite presents such a striking crystallographic similarity, was discovered by Koksharov in the Ilmen Mountains, Urals, in 1854, and has long been considered as a doubtful variety of rutile. Recently, however, it has been raised to the rank of a definite species by Brögger,[1] who has published the following analyses of Norwegian specimens, one of which agrees very closely with the analysis of the original mineral from the Ilmen Mountains, made by R. Hermann in 1866.

	Ilmen Mts. (Hermann.)	Evje, Norway. (Heidenreich.)	Tvedestrand, Norway. (Heidenreich.)
TiO_2	66·90	73·78	67·68
SiO_2	1·37	0·23	0·05
SnO_2	0·89	—	—
Nb_2O_5	19·64	13·74	20·31
Ta_2O_5	—	0·43	—
FeO	10·18	11·58	11·68
MnO	0·77	trace	trace
MgO	—	0·04	trace
CaO	—	0·22	0·28
	99·75	100·02	100·00
Sp. gr.	4·92	4·70–4·71	4·71

[1] W. C. Brögger, 'Die Mineralien der südnorwegischen Granit-Pegmatitgänge. I. Niobate, Tantalate, Titanate und Titanoniobate.' Videnskabs-Selskabets Skrifter, Math.-Naturv. Klasse, 1906, no. 6, p. 41.

According to these analyses, ilmenorutile presents no very close relationship with strüverite in quantitative chemical composition. The percentage of titanic acid is considerably higher, while the niobic acid is present in much too small amount to unite (as in strüverite) with all the ferrous oxide to form the molecule $FeNb_2O_6$. It will be noticed, however, in the case of the two Norwegian specimens having the same specific gravities, that the analyses only differ in the relative amounts of the titanic and niobic acids. The idea was therefore suggested that the separation of the two acids had been incomplete, and in view of the results of the preceding investigation it seemed probable that in all three analyses the titanic acid had been determined gravimetrically, and that a large proportion of what was weighed as titanic acid consisted really of niobic acid which had passed into solution after the fusion of the minerals with acid sulphate of potassium. To test this idea, colorimetric determinations were made on a specimen of ilmenorutile from the Ilmen Mountains in the Koksharov Collection in the British Museum, and also on a specimen of the mineral from Evje which was kindly supplied by Professor Brögger. The results were as follows:—

	Ilmen Mts.	Evje.
TiO_2 ...	53·04 ...	54·50

Taking these numbers for the titanic acid and adding the differences from the old numbers to the niobic acid, we have the following corrected results:—

	Ilmen Mts.	Evje.	Tvedestrand.
TiO_2 ...	53·04 ...	54·50 ...	54·50
SiO_2 ...	1·37 ...	0·23 ...	0·05
SnO_2 ...	0·89 ...	— ...	—
Nb_2O_5, Ta_2O_5 ...	33·50 ...	33·02, 0·43 ...	33·49
FeO ...	10·18 ...	11·58 ...	11·68
MnO ...	0·77 ...	— ...	trace
MgO ...	— ...	0·04 ...	trace
CaO ...	— ...	0·22 ...	0·28
	99·75	100·02 ...	100·00

As further confirmation of these results, complete quantitative analyses were made of the specimen from the Ilmen Mountains; and of one from Iveland, Norway, for which I am also indebted to the kindness of Professor Brögger. The results are as follows:—

	Ilmen Mts.	Molecular ratios.	Iveland.	Molecular ratios.
TiO_2 ...	53·04	0·663	54·57	0·682
Nb_2O_5 ...	21·73	0·081	32·15 [1]	0·120
Ta_2O_5 ...	14·70	0·033	—	—
FeO ...	10·56	0·147	12·29	0·170
CaO ...	trace	—	0·11	
MgO ...	—	—	trace	
	100·03		99·12	
Sp. gr. ...	5·14 [2]		4·64 [3]	

Weight of material used in the analysis of the mineral from the Ilmen Mountains, 0·5413 gram; in that of the mineral from Iveland, 1·1073 gram.

The analysis of the mineral from Iveland was conducted by methods similar to those used in the case of strüverite. Preliminary analyses of the Russian mineral were also made in the same way. In one of these the amount of tantalic and niobic acids in the insoluble residue left on treating with water the melt from the fusion with acid potassium sulphate was only about 14 per cent., and in another only about 12 per cent. In the final analysis of the Russian mineral, the result of which is given above, no attempt was made to separate the niobic and tantalic acids from the titanic acid. They were all precipitated together, and the tantalum (mixed with titanium) was separated from niobium (mixed with titanium) by Marignac's method, as described in the case of strüverite on p. 83. After the colorimetric determination of the titanium in the two sulphuric acid solutions, the total weight of niobic and titanic acid in the one, and of tantalic and titanic acid in the other, was determined by driving off most of the sulphuric acid, diluting, and precipitating by long-continued boiling.

[1] Of this percentage of niobic acid as much as 25·22 passed into solution with the titanic acid. The loss in the analysis is probably partly due to loss of niobic acid in washing the ammonia precipitate, and partly to loss on evaporation with hydrofluoric acid in testing for tantalic acid by Marignac's method: no needles of the tantalum salt were obtained.

[2] Determined on 0·5310 gram of material. The specific gravity of a mixture (corresponding to the above analysis) of 55 parts of rutile (sp. gr. = 4·2), 19 parts of tantalite (sp. gr. = 7·3), and 28 parts of columbite (sp. gr. = 5·3) would be 5·10.

[3] Determined on 1·3497 gram of material. The specific gravity of a mixture (corresponding to the above analysis) of 55 parts of rutile (sp. gr. = 4·2) and 45 parts of columbite (sp. gr. = 5·3) would be 4·69.

The simplest formula suggested by the above analyses of ilmenorutile is $FeO.Nb_2O_5.5TiO_2$, the calculated percentages for which are given below under I. Closer agreement between the amounts found and calculated are obtained when we assume an admixture of the molecule $FeTiO_3$ (as suggested by Brögger) or of $FeTi_2O_5$, molecules such as may be present in the ferriferous rutiles.[1] On this assumption, the formula of the ilmenorutile from the Ilmen Mountains would be

$$3{\cdot}5\,[FeO.(Nb_{\frac{5}{7}},Ta_{\frac{2}{7}})_2O_5.5TiO_2]+FeTi_2O_5,$$

and of that from Iveland

$$2{\cdot}4\,[FeO.Nb_2O_5.5TiO_2]+FeTi_2O_5.$$

The calculated percentages corresponding to these formulae are given under II and III respectively.

	I.	II.	III.
TiO_2 ...	54·06	52·00	55·60
Nb_2O_5 ...	36·21	22·33	32·15
Ta_2O_5 ...	—	14·87	—
FeO ...	9·73	10·80	12·25
	100·00	100·00	100·00

Relation of strüverite to ilmenorutile.

The preceding analyses show the close chemical relationship of strüverite and ilmenorutile. The simplest formula deducible from the analyses is for strüverite $FeO.(Ta,Nb)_2O_5.4TiO_2$ and for ilmenorutile $FeO.(Nb,Ta)_2O_5.5TiO_2$. The experiments described on p. 83 suggest that niobium, tantalum, and titanium readily form complex combinations[2] which render the analytical separation of these three elements so difficult. Strüverite and ilmenorutile might naturally therefore be regarded as salts of complex titan-niobic and titan-tantalic acids, represented by the above formulae, and related to each other as polycrase to euxenite or blomstrandine to priorite.[3] This view of the

[1] The experience of the solubility of niobic and tantalic acids in presence of excess of titanic acid, which was gained in the analyses of strüverite, naturally suggested the idea that possibly the iron in ferriferous rutiles might be combined with niobic and tantalic acids, and that these acids might have been previously overlooked. A colorimetric determination, however, of the titanic acid in a specimen of nigrine from Transylvania gave the number 96 per cent., and thus lent no support to this view.

[2] This view has already been expressed by W. Prandtl, Zeits. Kryst. Min., 1905, vol. xl, p. 395.

[3] W. C. Brögger, 1906, loc. cit.

chemical composition of the minerals would be in accordance with the very close agreement in percentage composition of the Norwegian specimens from three distinct localities and of the mineral from the Ilmen Mountains, but it fails to explain satisfactorily the very close crystallographic similarity of the minerals with tapiolite, mossite, and rutile.

On the whole, therefore, until analyses by improved methods have been made of materials from other localities, it seems best for the present to regard all three minerals, from Italy, Russia, and Norway, as essentially solid solutions of the tapiolite or mossite molecule $Fe[(Ta,Nb)O_3]_2$ with the rutile molecule $TiO.TiO_3$. In support of this view may be mentioned the fact that some of the small crystals of ilmenorutile from the Ilmen Mountains, when viewed in bright sunlight, show on certain faces minute patches of transparent red rutile in absolute crystallographic continuity with the prevailing black and opaque mineral.

According to this view of the chemical composition, we propose to reserve the name strüverite for those members of the series which are rich in tantalic acid, and to keep the name ilmenorutile for those, like the Norwegian specimens, in which niobic is the prevailing acid. Strüverite and ilmenorutile thus bear somewhat the same relation to each other as tapiolite (rich in tantalic acid) to mossite (rich in niobic acid). In accordance with its high percentage of tantalic acid, strüverite has a much higher specific gravity (5·59) than the Norwegian ilmenorutile (4·69). It has also a slightly higher axial ratio (1 : 0·6456) as compared with the axial ratio of the mineral from the Ilmen Mountains (1 : 0·6436), just as tapiolite has a higher axial ratio (1 : 0·6525) than mossite (1 : 0·6438).

NOTES.

The following deaths have to be recorded :—

Johann Friedrich Carl Klein (1842–1907) was an honorary member of several scientific societies, and was elected to the Mineralogical Society in 1895. He was successively professor of mineralogy at Heidelberg (1873–7), Göttingen (1877–87), and Berlin (1887–1907). The mineralogical papers, which appeared regularly each year ever since 1869, were not the only results of his work, for he devoted much time to increasing and arranging the collections under his charge at Göttingen and Berlin ; and at one time (1879–84) he was one of the joint editors of the 'Neues Jahrbuch für Mineralogie, &c.' He determined the crystallographic and optical characters of a large number of minerals and organic substances, but his most important work was on the optical characters of pseudo-symmetric substances, and the action of heat on these characters ; in this direction he added considerably to our knowledge of boracite, leucite, garnet, apophyllite, &c. Later, he turned his attention to meteorites, and he was the first to recognize the presence of leucite in these bodies. He also designed an elaborate instrument, which he called a polymeter, and which is a combination of a three-circle goniometer, polariscope, axial angle apparatus, &c., in fact, of all the instruments required for the determination of the constants of crystals.

Carl Klein died on June 23, 1907. A detailed biographical notice, with portrait and list of his published papers, is given by Professor F. von Wolff, one of his former assistants, in the 'Centralblatt für Mineralogie, &c.' (1907, pp. 641–661). His successor at Berlin is Professor T. Liebisch of Göttingen.

Bernard James Harrington (1848–1907), Professor of Chemistry and Mineralogy in McGill University, Montreal, was well known on account of his work in chemical mineralogy. He was a Canadian by birth, and after studying at McGill University and the Sheffield Scientific School of Yale University (where he gained the prize in mineralogy), he was, in 1871, appointed lecturer in chemistry and mineralogy at McGill University. In 1872 he succeeded Dr. T. Sterry Hunt as chemist and mineralogist to the Geological Survey of Canada, retiring from this

position in 1879, in order to devote himself entirely to teaching; his appointment as professor at McGill University dated from 1883. He died after a long illness on November 29, 1907.

The list of his published papers is not a long one, but what he did was done thoroughly. His first mineralogical paper, published in 1874, was on a new mineral which he named dawsonite (after Sir J. William Dawson, Principal of McGill University, whose daughter he married); and his last, on isomorphism in magnetite, was published in this magazine only shortly before his death.

Giuseppe Grattarola (1844–1907), Professor of Mineralogy in the R. Istituto di studi superiori of Florence, died on March 23, 1907. A notice of his work on Italian minerals is given in Atti Soc. Toscana Sci. Nat., 1907 (Proc. verb., vol. xvi, pp. 44–49). The minerals beccarite, hydrocastorite, oryzite, pseudonatrolite, and rosterite, were described and named by him.

Alfonso Sella (1865–1907), Professor of Experimental Physics in the Royal University of Rome. His father, Quintino Sella (1827–84), after whom the mineral sellaite was named, was perhaps better known to mineralogists, but the son was also author of several papers on minerals and on the physical properties of crystals.

On the occasion of the centenary celebrations of the Geological Society of London the following address was presented by the President of the Mineralogical Society. The address was printed in one of the larger founts of the famous 'Bishop Fell' type, the matrices for which were presented to the University Press at Oxford by Bishop Fell about 1670. The following reprint is in a smaller italic type of the same kind.

The 'British Mineralogical Society' referred to in the address was founded in 1799, and was a forerunner of the Geological Society. The list of twenty-five members includes many well-known names of early mineralogists, amongst them A. Aikin, W. Allen, W. Babington, W. H. Pepys, R. Phillips, and, amongst the corresponding members, R. Kirwan. The MS. minute book of the society is now in the library of the Victoria and Albert Museum, and the proceedings were published in Tilloch's 'Philosophical Magazine'. Further particulars about the society will be found in H. B. Woodward's 'History of the Geological Society of London' (1907) and in this Magazine (vol. xi, p. 184).

To the Geological Society of London

N offering to the Geological Society of London an address of congratulation upon a century of existence rich in Scientific activity, the Mineralogical Society is not unmindful of the debt of gratitude which Mineralogy owes to the Geological Society. Several of the founders of the Geological Society had previously initiated the first British Society of Mineralogy, and the work of the Geological Society for several years was mainly in the field of Mineralogical Research; in fact the principal object for which the Society was instituted was the advancement of Geological Science 'as connected with the Mineral History of the British Isles'.

During the latter half of the nineteenth century other aspects of Geology so occupied the attention of the Society that, except in the field of Petrology, Mineralogical investigation has been less pursued by its Fellows. But the Society has always encouraged Mineralogists and welcomed their work. This encouragement has been extended in a very special manner to the Mineralogical Society of Great Britain and Ireland, which for the last eighteen years has enjoyed the kindly hospitality of the Geological Society, and has been allowed to hold its meetings in the apartments at Burlington House.

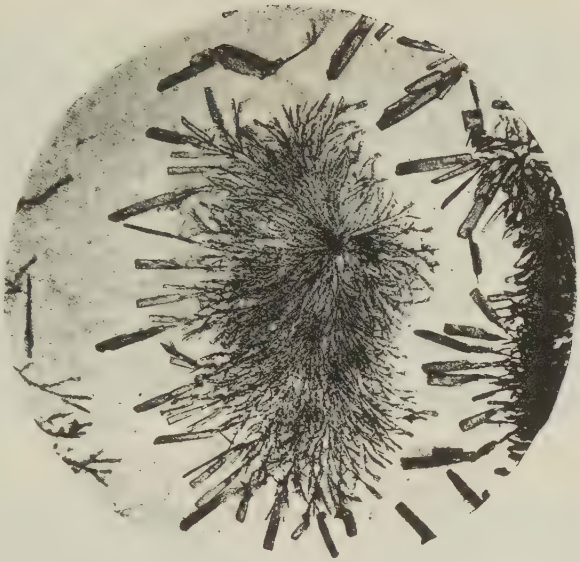
It is therefore with feelings of deep gratitude that the Mineralogical Society offers its congratulations to the Geological Society upon the brilliant career which it has pursued during the last hundred years, and expresses the hope that the Society may long continue to flourish and to labour successfully in the promotion of Geological and Mineralogical Science.

Signed on behalf of the Mineralogical Society

HENRY A. MIERS

September 25, 1907 *President*

1



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H. A. Miers: Crystallization of Potassium Bichromate.

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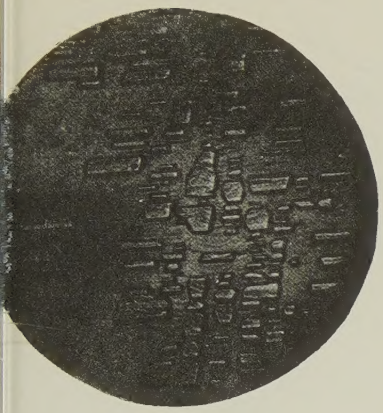

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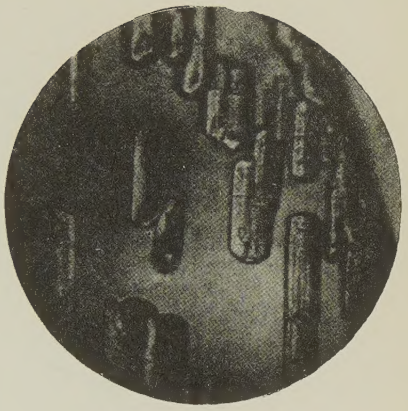

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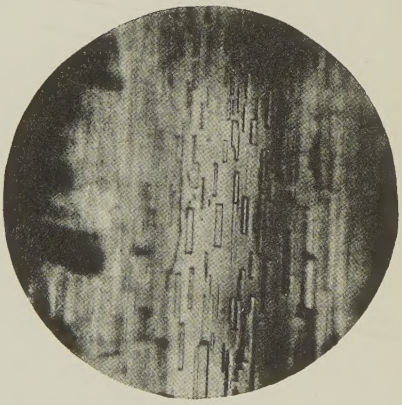

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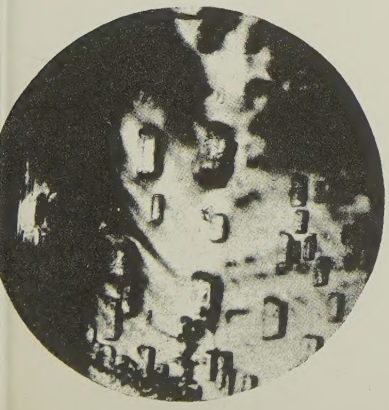

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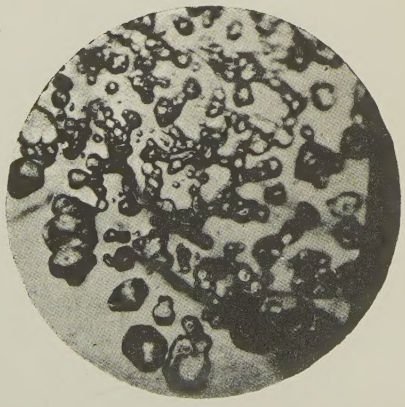

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